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REPLY TO
ATTENTION OF

April 25, 2000

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Mr Craig Zeller
U S Environmental Protection Agency
Region 4
Atlanta Federal Center
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Atlanta, Georgia 30303-8960

Dear Mr Zeller

Enclosed is the final letter report summarizing sediment transport studies on Twelve Mile Creek and Lake Hartwell conducted by the Engineer Research and Development Center, Coastal and Hydraulics Laboratory

If you have any further questions concerning the work, please contact the principal investigator, Dr Steve Scott, at (601) 634-2371

Thomas J. Pokrefke

for James R Houston, PhD
Director
Coastal and Hydraulics Laboratory

Enclosure

10115908

ERDC SEDIMENT TRANSPORT STUDIES ON TWELVE MILE CREEK AND LAKE HARTWELL IN SUPPORT OF THE EPA SELECTED REMEDY

by

Stephen H Scott

Engineer Research and Development Center
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April 2000

Final Report

Prepared for the United States Environmental Protection Agency, Region 4

Enclosure

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PREFACE

This study was conducted by the Coastal and Hydraulics Laboratory (CHL) of the U S Army Engineer Research and Development Center (ERDC) The study was sponsored by the United States Environmental Protection Agency (EPA), Region 4 Mr. Craig Zeller was the EPA technical monitor for the study.

This report was prepared by Dr Stephen H. Scott of the River Sedimentation and Engineering Branch of the Rivers and Structures Division. The field data collection effort was coordinated and performed by RMT, Inc. of Greenville, South Carolina

The study was conducted under the general supervision of Dr James Houston, Director of CHL; Mr. Tom Richardson, Deputy Director, CHL; and Dr Yen Hsi Chu, Chief, River Sedimentation Engineering Branch.

ERDC SEDIMENT TRANSPORT STUDIES ON TWELVE MILE CREEK AND LAKE HARTWELL IN SUPPORT OF THE EPA SELECTED REMEDY

INTRODUCTION

Portions of Twelve Mile Creek and Lake Hartwell contain PCB contamination resulting from the operation of a capacitor manufacturing facility located in the upstream watershed of Twelve Mile Creek In June 1994, the EPA issued a Record of Decision (ROD) for this site, referred to as the Sangamo OU2 Site This ROD addressed the sediment, surface water, and sediment transport pathways from land based source areas adjacent to the capacitor manufacturing facility.

To address the sediment contamination problem in Twelve Mile Creek and Lake Hartwell, the EPA's selected remedy is to use the natural sedimentation processes of Twelve Mile Creek to deliver sediment to the contaminated areas, thus providing a clean sediment cap on top of the contaminants to prevent further resuspension and transport of PCB through the creek and lake system.

BACKGROUND

The natural sediment transport process in Twelve Mile Creek is altered by three reservoirs on the creek system Woodside I and II which are hydropower reservoirs, and a water supply reservoir These reservoirs store the coarse fraction of the incoming sediment load until either dredging or flushing operations are performed The stored sediments are periodically flushed and dredged from the reservoirs and subsequently deposited downstream of Woodside II. It is anticipated that during periods of increased flows in Twelve Mile Creek, the sediments will migrate to the backwater of Lake Hartwell and provide a protective cap on top of the contaminated sediments

The EPA has funded the Engineering Research and Development Center (ERDC) to evaluate the sediment transport processes of Twelve Mile Creek and the fate of sediment discharged from flushing and dredging operations Additional tasks to be included in the effort are an estimation of costs involved in extending the dredge pipeline five miles below the hydropower reservoirs and a study of using a hydrosuction pipeline as an alternative to hydraulic dredging for bypassing sediments across the hydropower reservoirs.

In 1993, the Bechtel Corporation conducted sediment transport studies on Twelve Mile Creek using the HEC-6 one-dimensional computer model The studies were designed to predict sediment transport (spatial and quantitative erosion and deposition) along a reach of Twelve Mile Creek extending from just below the Woodside II hydropower reservoir to the highway 37 bridge spanning Lake Hartwell A 30 year simulation was conducted to evaluate if natural sediment transport in Twelve Mile Creek could deliver clean sediments for capping PCB contaminated areas in the downstream reaches of the creek and Lake Hartwell backwater Additionally, a large sediment flushing event was monitored by Bechtel The HEC-6 program was used to predict the fate of the flushed sediments This effort is summarized in this report

The ERDC effort described in the main body of this report was a continuation of the Bechtel modeling effort. The HEC-6 model was once again used to simulate the hydraulic and sediment processes of Twelve Mile Creek The simulation period was from April 1992 through September of 1999 Sections of Twelve Mile Creek were re-surveyed for comparison to the Bechtel surveys of 1992 Additionally, to support the modeling effort, bed sediment samples were collected for particle size analysis The survey comparisons and bed sample particle size analysis are included in Appendices C and D of this report

The ERDC simulation included both flushing and dredging events that occurred over the period In addition to the modeling effort, two additional problem areas were addressed. The dredging operations on Twelve Mile Creek use a hydraulic dredge to pump sediments from the upstream reservoirs to a point just downstream of Woodside II During low water, the dredged sediments temporarily accumulate in the channel, thus impact habitat and recreational use of the creek It was proposed by concerned citizens and natural resource trustee's to bypass the sand five miles downstream of Woodside II directly into Lake Hartwell To investigate this, a cost analysis was conducted by the ERDC to investigate the feasibility of lengthening the pipeline. The results of this study are presented in Appendix A of this report

The cost of current dredging operations for bypassing sediment from the upstream reservoirs is approximately $250,000 per year. Hydrosuction sand by-passing was investigated as an alternative to the cost of mobilizing, maintaining, and operating a hydraulic dredge plant for sediment removal from the reservoirs Hydrosuction sand bypassing utilizes a siphon pipe to entrain and transport sediments from the reservoirs The advantage of the siphon is that it utilizes the potential head across the reservoir to drive the flow, unlike a dredge that requires a large centrifugal pump powered by a motor. The cost savings over a standard dredging operation are potentially significant The hydrosuction study is summarized in Appendix B of this report

OBJECTIVE

The objectives for the effort described in this report are as follows.

1) Define the sediment transport capability of the Twelve Mile Creek channel for the hydraulic conditions represented by the time period of April 1992 through September 1999

2) Evaluate both spatial and quantitative sediment erosion and deposition characteristics throughout the Twelve Mile Creek system over the time period of April 1992 - September 1999

3) Determine the fate of sediments flushed and dredged from the upstream reservoirs over the time period of April 1992 - September 1999

4) Evaluate cost effective alternatives to the current reservoir dredging operations and address perceived environmental impacts of sediment bypass on Twelve Mile Creek

SUMMARY OF PREVIOUS WORK BY BECHTEL

In 1991 Bechtel Environmental conducted a field investigation in the Twelve Mile Creek / Lake Hartwell area of South Carolina as part of the remedial investigation/feasibility study for the PCB-contaminated Sangamo Superfund site The field investigation included field surveys of Twelve Mile Creek crossections, bed sample collection and analysis, suspended sediment sample collection and analysis, and water quality sampling and analysis

Bechtel utilized the HEC-6 one-dimensional computer model to evaluate sediment transport in the Twelve Mile Creek channel, from just below the Woodside II hydropower reservoir to the highway 37 bridge that crosses Lake Hartwell about 10 miles downstream from Woodside II A listing of the crossections used in the Bechtel model is provided in Table 1 The model utilized 22 crossections (channel geometry) Thirteen of the crossections were surveyed, with the remaining estimated with the aid of topographic maps All of the section geometries in the upper reach of the study area were estimated (sections T12, T15, T16, T17, T18, and T19) The channel invert elevations were initially extrapolated from surveyed elevations, and then adjusted during calibration runs

Bed samples were collected at 11 sections, from section T1 (lower boundary section) to section P The sample size gradations were put into the HEC-6 model For the 6 sections above section P, the bed particle size gradation measured at section P was used The median grain size of the Bechtel samples ranged from <0 0075 mm at the lower boundary (T1) up to 0 125 mm at section P (the last section sampled)

The Bechtel analysis assumed a sediment supply reach just upstream of Woodside II. The fine sediment component of the sediment load rating curve was developed from suspended sediment samples taken from the Hwy 123, 93, and 133 bridges and Maw bridge. The sand fractions of the sediment load were determined from model verification procedures

Table 1 Crossection designations in the Bechtel HEC-6 model

SECTION	DISTANCE FROM T1 - ft
T1	0
A	4,000
B	12,000
C	15,000
*D	17,400
*T6	18,600
H	22,100
I	24,400
J	26,400
K	27,400
L	29,400
M	30,100
N	32,300
O	34,900
*T12	37,000
P	37,900
*Q	38,900
*T15	42,700
*T16	45,100
*T17	49,100
*T18	52,100
*T19	54,100

* Crossection geometry estimated

The Bechtel model was calibrated to Corps of Engineers sediment surveys conducted in 1963 and 1973 Channel geometry from 1963 was used in the HEC-6 model A ten-year simulation was run using main channel discharge measurements at the Liberty Bridge station, along with 5 tributaries entering the system between sections T19 and T1. The downstream boundary condition was the Lake Hartwell water surface elevation The sediment rating curve was iteratively adjusted until the Twelve Mile Creek bed profile matched that of the 1973 survey With the verified model, Bechtel then ran a 28 year simulation (from 1963 to 1991) to obtain the bed profile for their 1992 model study Using the HEC-6 model, they performed a number of simulations (10, 20, and 30 yr) to evaluate the sediment transport characteristics (deposition and erosion) below Woodside II. They found that the deposition of sands in the system occurred between sections T16 and M in the model, with only fine sediments depositing in the lower reaches of the Twelve Mile Creek system. This corresponded roughly with the range of Lake Hartwell water surface elevations that occurred over the course of the study. The complete HEC-6 study conducted by Bechtel is found in Appendix E

ERDC EVALUATION OF THE TWELVE MILE CREEK SYSTEM

The ERDC was tasked with conducting three studies to support the EPA on environmental restoration activities on Twelve Mile Creek and the backwater of Lake Hartwell. The three efforts include: 1) A HEC-6 one-dimensional modeling effort to define sediment transport characteristics of the Twelve Mile Creek system, 2) An evaluation of the impacts resulting from increasing the discharge pipeline length for the hydropower reservoir dredging ,and 3) An evaluation of the hydrosuction dredging method as an alternative to dredging In addition to the above described tasks, the ERDC worked with RMT, an environmental consulting firm that provided field surveys of Twelve Mile Creek crossections and bed and suspended sediment sampling The ERDC performed particle size analysis of the bed and suspended sediment samples.

RMT FIELD DATA COLLECTION

In support of the ERDC modeling effort, RMT surveyed twenty-one transects on Twelve Mile Creek in August of 1999 Additionally, RMT took 14 sets of bed samples in the study area for particle size analysis. Analysis results for the samples are found in Appendix D of this report. Each set contained samples from the left side, center, and right side of the channel. The samples were taken to a depth of 1 ft in the bed Additionally, when adequate discharge was available in the creek, suspended sediment samples were taken at the Liberty Bridge and Lay Bridge locations. The RMT field data collection activities and data are summarized in the RMT report titled "Twelve Mile Creek Sediment Transport Model/Data Collection Report", December 1999

HEC-6 MODELING EFFORT

The ERDC modeled sediment transport in the Twelve Mile Creek system using HEC-6, a one-dimensional computer program designed to evaluate hydraulic and sediment transport regimes in river systems A description of HEC-6 is found in the Bechtel report in Appendix E The upstream boundary of the model was the Woodside II hydropower reservoir (as was in the Bechtel study), with the downstream boundary being section T6. The total study reach distance was approximately 35,000 ft Table 2 presents the section designations along the study reach, along with the distance from the upper model boundary (T19) Figures 1 and 2 depict both the Lake Hartwell and Twelve Mile Creek sections of the study area with section designations. It was apparent from the Bechtel study that the reach of Twelve Mile Creek below section T6 would have minimal sediment accumulations, therefore the sections below T6 that were included in the Bechtel study were not included in the ERDC study

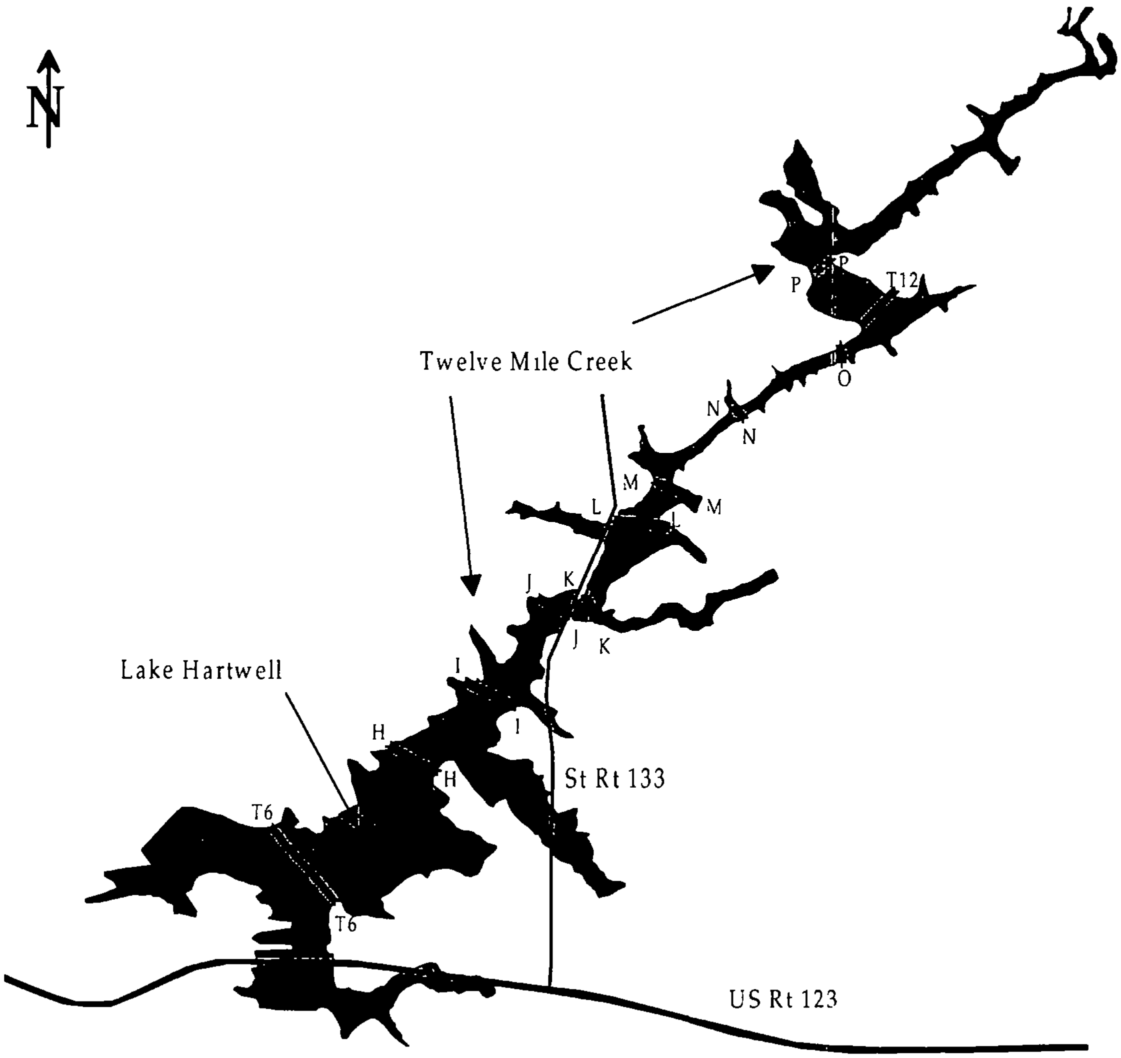


Figure 1 Crossection designations on Lake Hartwell / lower Twelve Mile Creek

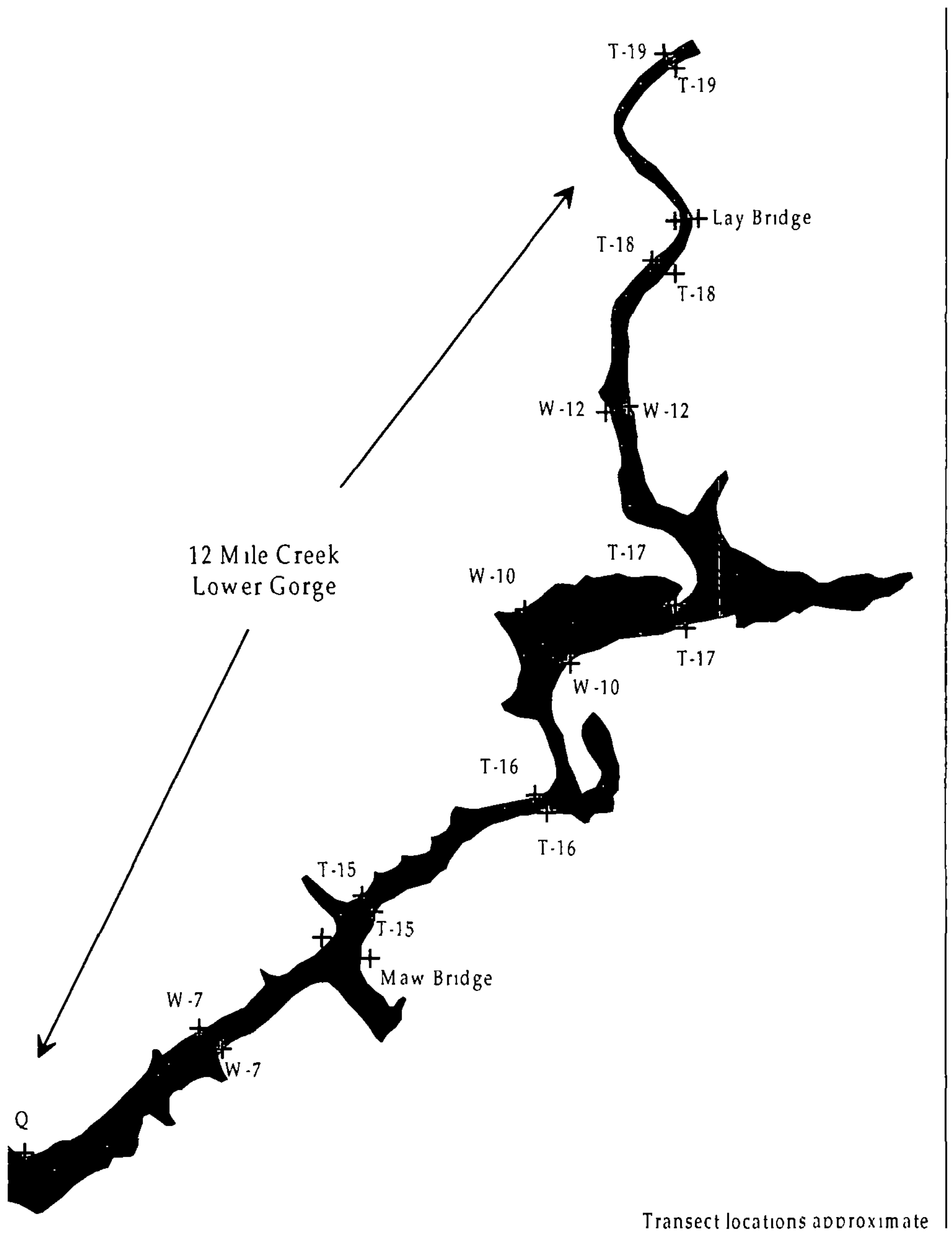


Figure 2 Crossection designations on upper Twelve Mile Creek

Table 2. Crossection designations in the ERDC HEC-6 model

SECTION	DISTANCE FROM T19 - ft
T6	35,000
H	32,000
I	29,700
J	27,700
K	26,700
L	24,700
M	24,000
N	21,800
O	19,200
T12	17,100
P	16,200
Q	15,200
T15	11,400
T16	9,000
T17	5,000
T18	2,000
T19	0

Model Channel Geometry and Bed Sediment Description

The channel geometry used in the Bechtel model was used in the ERDC study In the upper reaches of Twelve Mile Creek, Bechtel used bed sediment gradations from section P The ERDC study used actual bed gradations obtained from the RMT sampling effort for the upper sections of the study reach The generalized median size of sediments in Twelve Mile Creek is found in Figure 3 The median (D50) size ranges from approximately 1.0 mm at the USGS Liberty Bridge gauging station to <0 075 mm in the lower reaches of Twelve Mile Creek.

Upstream and Downstream Model Boundary Conditions

Discharge data for the ERDC study was obtained from the USGS Liberty Bridge gauging station This represented the upstream discharge boundary condition for the model Two additional inflows were included in the model These inflow locations were the same as used in the Bechtel study. They occurred above section P and section H in the model Because no discharge measurements were available for these tributaries, the discharge was estimated as the ratio of the tributary drainage area to Liberty Bridge gauging station drainage area multiplied times the Liberty Bridge discharge. The HEC-6 study was conducted over a seven year and five month period (April 1992 - September 1999). Discharge records from the USGS gauging station were obtained for

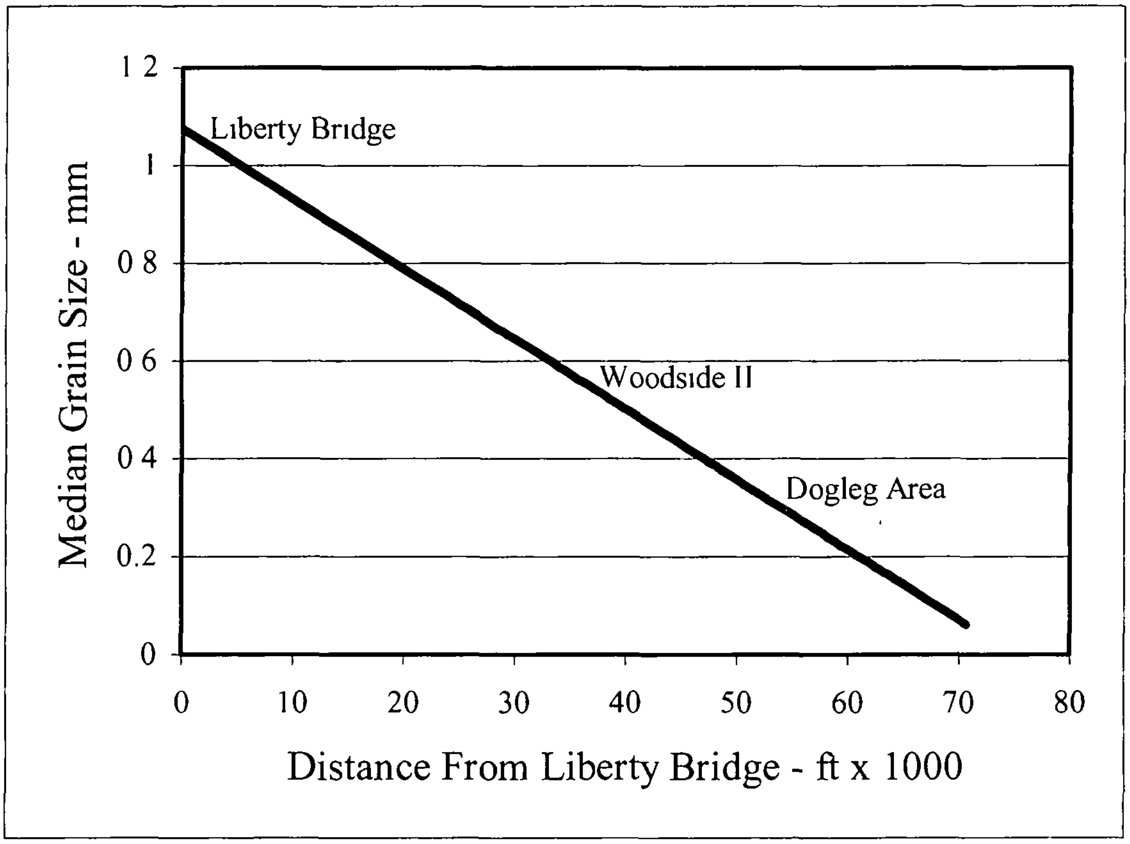


Figure 3. Generalized bed sediment median grain size for Twelve Mile Creek

this period (Figure 4) The downstream boundary condition for the HEC-6 model was the Lake Hartwell water surface elevation (WSE) The seven year, five month Lake Hartwell WSE was obtained from Lake Hartwell Dam, and is presented in Figure 5.

Main Channel and Tributary Sediment Input

The sediment rating curve used in the Bechtel study was used in the ERDC study Both of the tributaries input in the model were assumed to transport sediment The sediment size fractions for the sediment load curve used in the Bechtel study were slightly modified for the ERDC study to reflect the stable upper reaches of Twelve Mile Creek. This is discussed in more detail later in the report The Sediment rating curve is presented in Figure 6, with the Bechtel and ERDC sediment size fractions presented in Figure 7

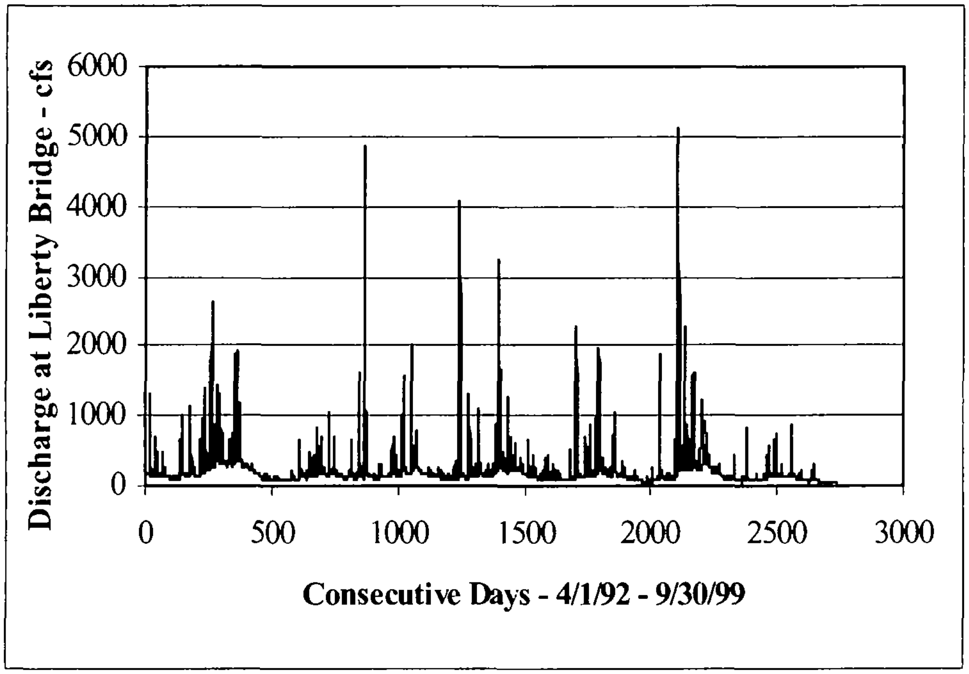


Figure 4 Liberty bridge discharge from April 1992 - September 1999

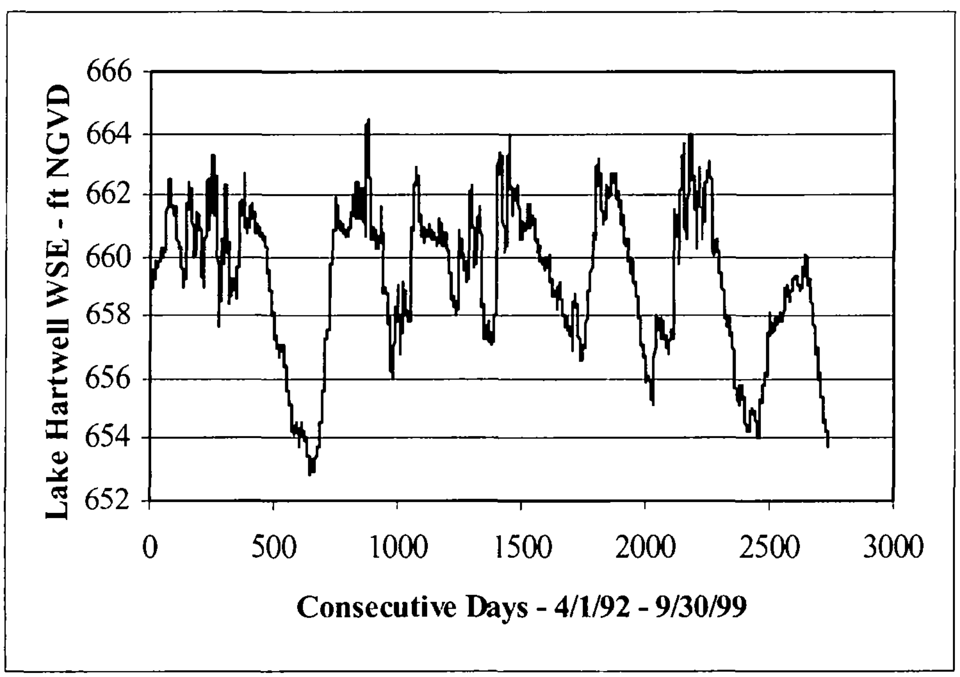


Figure 5 Lake Hartwell WSE from April 1992 - September 1999

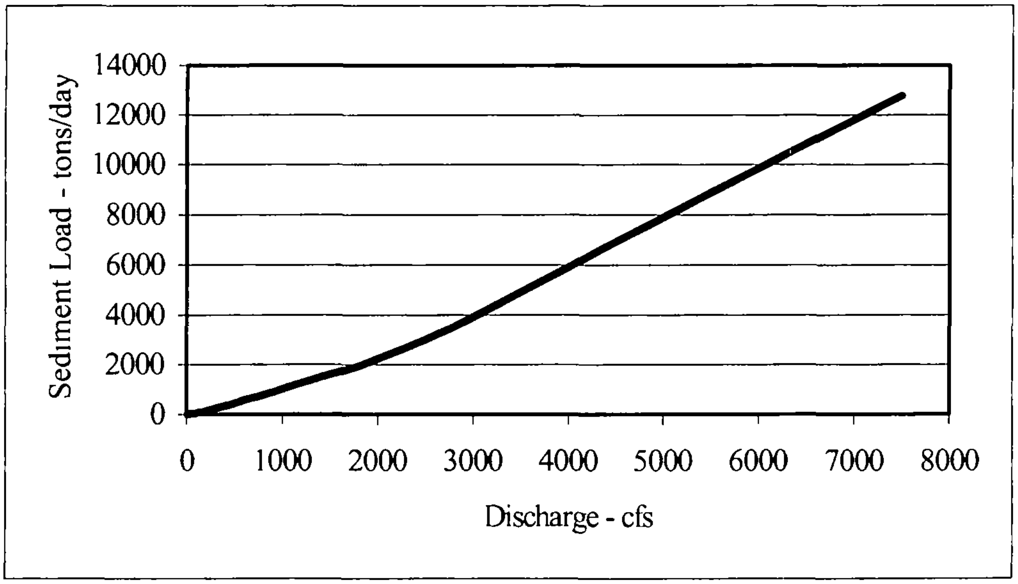


Figure 6. Bechtel and ERDC sediment rating curve

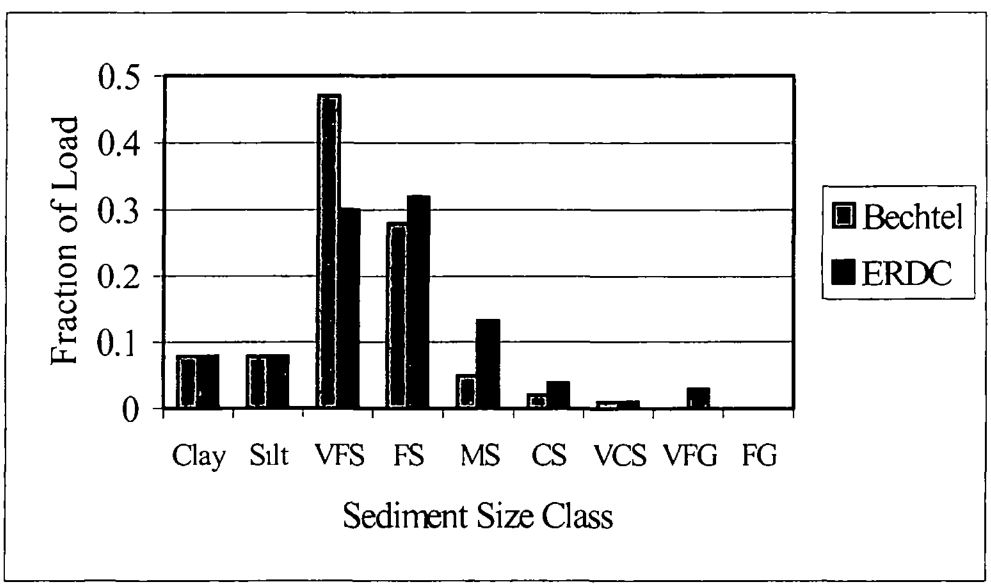


Figure 7 Sediment load size fractions for Bechtel and ERDC main channel sediment computations (VFS - very fine sand, FS - fine sand, MS - medium sand CS - coarse sand, VCS - very coarse sand, VFG - very fine gravel, FG - fine gravel)

Model Verification

Model verification was to be based on a comparison of the Bechtel channel surveys conducted in 1992 and the RMT channel surveys conducted in 1999 From these surveys, the deposition or erosion of the channel bed could be determined and compared to the model output Unfortunately, there were no benchmarks for the Bechtel survey locations, therefore RMT surveys could only be conducted in the same general location as Bechtel Comparison plots of the Bechtel and RMT transects are found in Appendix C The comparison plots indicate that in many cases, the crossection widths were significantly different, therefore computation of deposited quantities could not be determined In general, comparison of the channel invert elevations indicated that there was no significant deposition in the lower reaches of Twelve Mile Creek (section T6 to section M) In most of the comparison plots, the channel invert elevation of the RMT survey was somewhat lower than that of the Bechtel survey. Only one section indicated a significant, relatively constant depositional trend, section Q, as presented in Figure A10. It indicated an average deposition of approximately 4 4 ft across the transect width common to each survey. The upper reach transect geometries (T15 – T19) were not based on survey data in the Bechtel study, so no comparisons were made

Model Simulations - Description and Results

Because the model could not be completely verified by field measurements, a series of HEC-6 sensitivity model runs were conducted to evaluate spatial and quantitative sediment deposition within the study area. The Bechtel model was originally verified for sediment transport below Woodside II, therefore, these sensitivity runs should adequately represent hydraulic and sediment transport conditions over the study period (April 1992 – September 1999) The model runs and the results are presented in Table 3. A description and results for each run are provided below

Run 1 - seven year, five month simulation with the Bechtel sediment rating curve

This run essentially used the HEC-6 input data from the Bechtel study with the ERDC bed sample size gradations included in the upper reaches of Twelve mile creek. The results from this run indicated erosion of the bed in the upper reaches of Twelve mile creek (section T16 – section T19) Field observations indicate that the upper reaches of Twelve Mile Creek are relatively stable, with no channel incision, bank erosion, or bank failures evident.

Run 2 - seven year, five month simulation with a more coarse sediment load gradation to reflect a stable channel

To better represent a stable channel, the sediment size fractions of the Bechtel sediment rating curve were adjusted to reflect a more coarse sediment load. This minimized instability in the upper reaches, thus better representing the actual channel

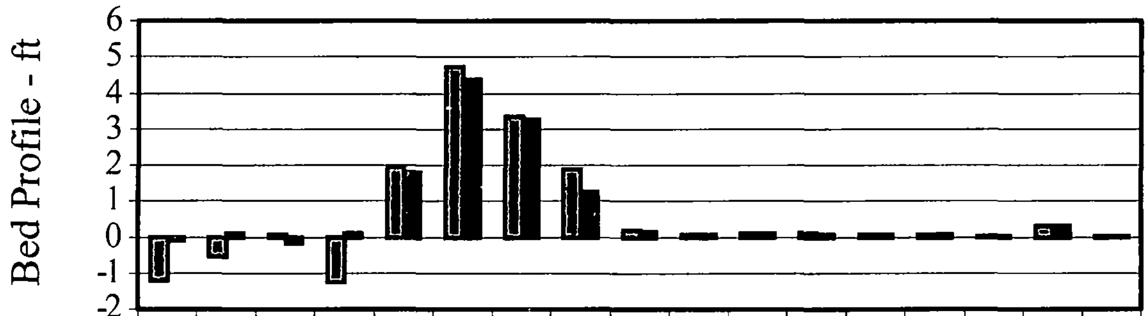
Table 3 Summary of HEC-6 model simulations

Model Run	Description	Purpose
1	Bechtel rating curve run	Evaluate bed profiles
2	ERDC rating curve run with coarsened gradations	Simulate stable upper channel reaches
3	Flushing and Dredging Simulation	Evaluate spatial and quantitative impacts
4	Evaluation of impact of 100 cfs flushing discharge	Evaluate spatial and quantitative impacts
5	Evaluation of impact of 500 cfs flushing discharge	Evaluate spatial and quantitative impacts
6	Run with Madden sediment transport equation	Sensitivity run to evaluate change in deposition patterns
7	Run with Toffaleti sediment transport equation	Sensitivity run to evaluate change in deposition patterns
8	Evaluation of the impact of doubling the sediment load	Sensitivity run to evaluate change in deposition patterns
9	Evaluation of the impact of halfing the sediment load	Sensitivity run to evaluate change in deposition patterns
10	Evaluation of the impact of doubling the fine sediment load	Sensitivity run to evaluate change in deposition patterns

condition The change in bed profile for runs 1 and 2 is presented in Figure 8 The top scale on the x-axis of the plot indicates the distance from the upper boundary (T19) The two bottom scales present the actual values of the change in bed profile in feet. The coarsening of the sediment load resulted in minimal deposition and erosion in the upstream reaches, with a small change in bed profile for sections T16 - T12

The model predicts that all of the sand fraction will be deposited between sections T16 and O, with only fines accumulating in the lower reaches of Twelve Mile Creek. The maximum depth of deposited sediment occurred in section Q (4 4 ft) The average depth of accumulation from sections T12 – T15 is approximately 2 7 ft.

The spatial and quantitative distribution of sediment compares favorably with the 1993 Bechtel model results and the Corps of Engineers survey data The results from the US Army Corps of Engineers surveys of 1963 – 1973 indicated that the average change in bed profile for sections T16 – O (deposition) would be approximately 3 0 feet every ten years Both the Corps surveys and the Bechtel model results agreed with the ERDC model that there would be very little change in bed profile below section T12 of Twelve Mile Creek The survey comparison for section Q (Figure 10A) indicates a deposition of approximately 4 4 ft, which is in excellent agreement with the model results.



	0.0	2.0	5 0	9 0	11 4	15 2	16.2	17 1	19.2	21 8	24	24 7	26.7	27 7	29 7	32	35 5
Bechtel	-1 2	-0.54	0.06	-1 23	1 96	4 73	3 33	1 87	0.16	0.06	0.1	0.08	0.06	0.05	0.03	0.31	0.02
ERDC	-0.1	0.1	-0.19	0.08	1 79	4 38	3 25	1 26	0.12	0.05	0.09	0.07	0.05	0.05	0.03	0.31	0.02

Distance from T19 - ft x 1000 - (Top Scale)

Bechtel ERDC

Figure 8 Change in bed profile for model runs 1 and 2

Run 3 - incorporation of flushing and dredging events into the 7 year simulation

To examine the impact of flushing and dredging sediments from the upstream reservoirs, the HEC-6 model was modified to reflect periodic releases of sediment into the Twelve Mile Creek system from flushing and dredging events. A major flushing event was undertaken on September 9, 1993 Forty three thousand cubic yards of sediment were flushed from the Woodside II sluice gate into Twelve Mile Creek just below the dam For the model simulation, a discharge of 300 cubic feet per second was assumed constant for the three day flushing event This was based on a static head of approximately 30 ft above the sluice gate driving the flow Two dredging events took place. The first occurred on October 15, 1998 Approximately 7,000 cubic yards of sediment were pumped from Woodside II to a discharge point just above Lay Bridge over a time period of 29 days The discharge through the pipe was estimated at 2000 gallons per minute (gpm) The second dredging event was conducted over the time period of July 7, 1999 – August 8, 1999, with 10,000 cubic yards of sediment released just above Lay Bridge. The discharge from the dredge pipe was also assumed to be 2,000 gpm The sediment size fraction used for the flushing and dredging simulations was based on bed samples taken in the immediate vicinity and just downstream of the dredge discharge pipe. These sample locations are designated as HB-5, HB-6, BS-8, BS-8A, and BS-8B in Appendix D Table 4 summarizes the sediment discharge events. Figure 9 presents the sediment size fraction that represents the flushed and dredged sediment.

Table 4. Flushing and dredging events for model run 3

EVENT	DURATION - days	TOTAL VOLUME - cu yd	* DELIVERY RATE - tons/day
Flushing	3	43,000	17,995
1st Dredging	29	7,000	303
2nd Dredging	33	10,000	380

* Delivery rate is based on a deposited sediment density of 93 lb/ cu ft

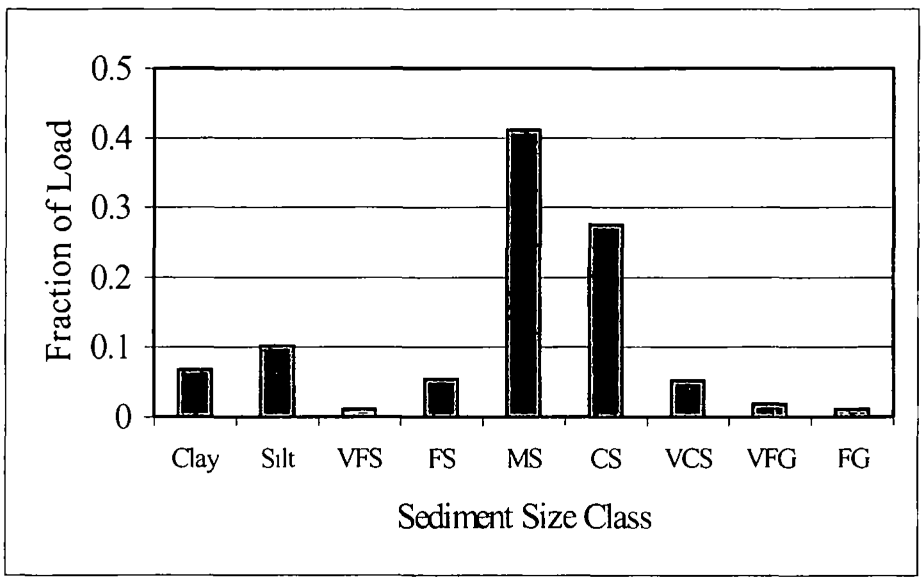
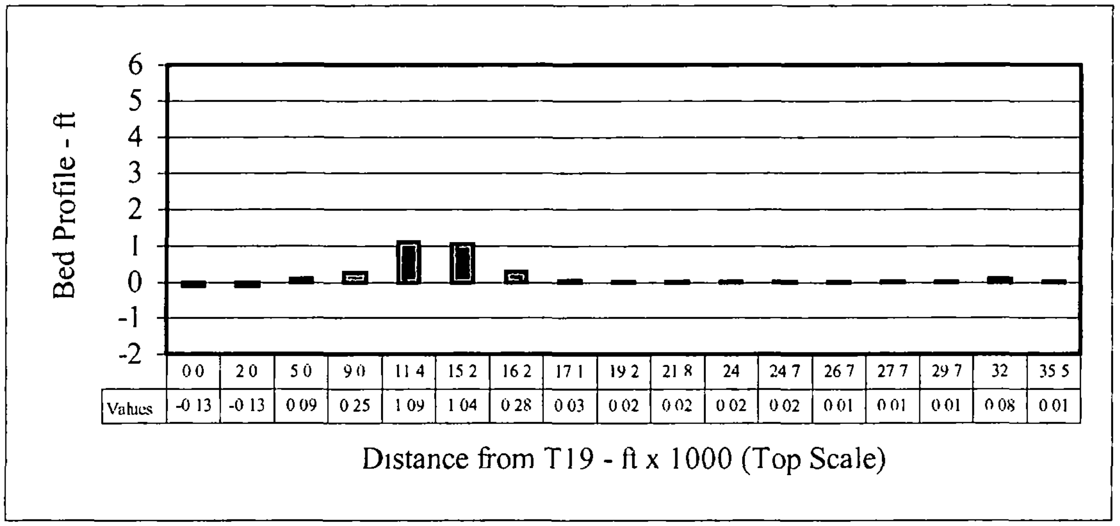


Figure 9. Sediment size fraction for the flushed and dredged sediment

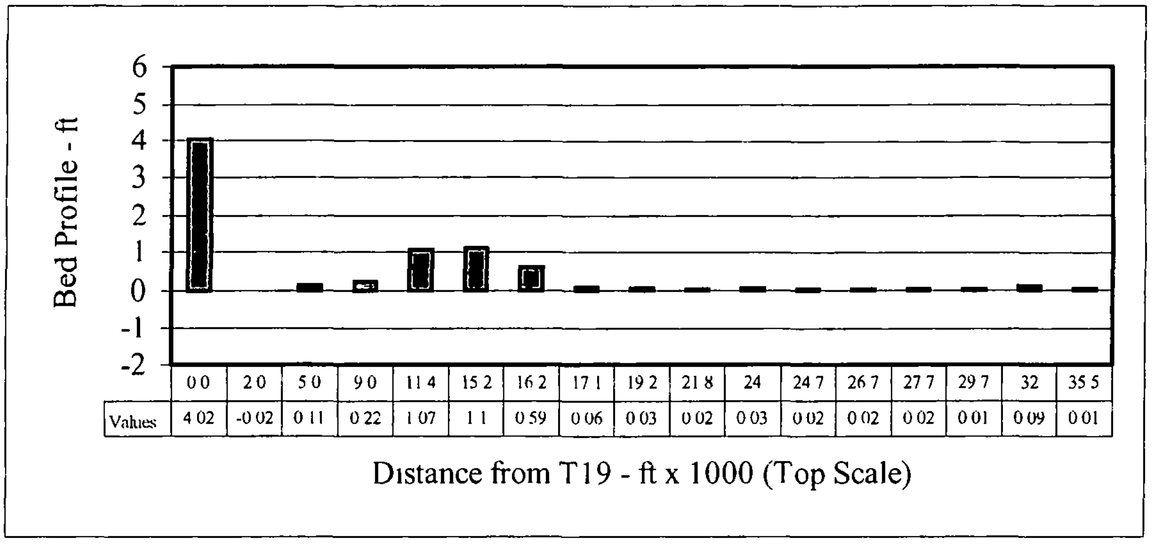
The impact of the flushing and dredging events is presented in terms of the change in bed profile along the study section of Twelve Mile Creek (sections T6 – T19) Model output is presented in Figures 10 – 24. Figures 10 – 16 present the change in bed profile before and after each flushing and dredging event, along with the final bed profile at the end of the simulation Figures 17– 24 present the fate of the deposited sediments over time for the upper sections of 12 mile creek (sections T19 – Q)

Figure 11, the bed profile just after flushing, indicates a deposition of approximately 4.0 feet just below Woodside II immediately after the flushing event Just before the first dredging event in October of 1998 (Figure 12), the flushed sediment accumulated below Woodside II has migrated to the downstream reaches, with the lay bridge transect having an increase in bed elevation of 0 16 ft Figure 13 presents the bed profiles just after the completion of the 7,000 cubic yard dredging event The bed elevation at Lay Bridge after the event was approximately 0 40 ft The next dredging event occurred in July of 1999, with the resulting bed profile presented on Figure 15 The bed elevation at the Lay Bridge transect was approximately 0 75 ft. The final bed elevation is shown in Figure 16. The change in bed elevation for Lay Bridge remains approximately 0.75 ft The spatial and quantitative change in bed elevation for sections T16 – O are very similar to bed elevations resulting from the first two model runs, with the maximum bed change occurring at section Q (4 5 ft)



	0 0	2 0	5 0	9 0	11 4	15 2	16 2	17 1	19 2	21 8	24	24 7	26 7	27 7	29 7	32	35 5
Values	-0 13	-0 13	0 09	0 25	1 09	1 04	0 28	0 03	0 02	0 02	0 02	0 02	0 01	0 01	0 01	0 08	0 01

Figure 10 Bed profile just before flushing event



	0 0	2 0	5 0	9 0	11 4	15 2	16 2	17 1	19 2	21 8	24	24 7	26 7	27 7	29 7	32	35 5
Values	4 02	-0 02	0 11	0 22	1 07	1 1	0 59	0 06	0 03	0 02	0 03	0 02	0 02	0 02	0 01	0 09	0 01

Figure 11 Bed profile just after flushing event

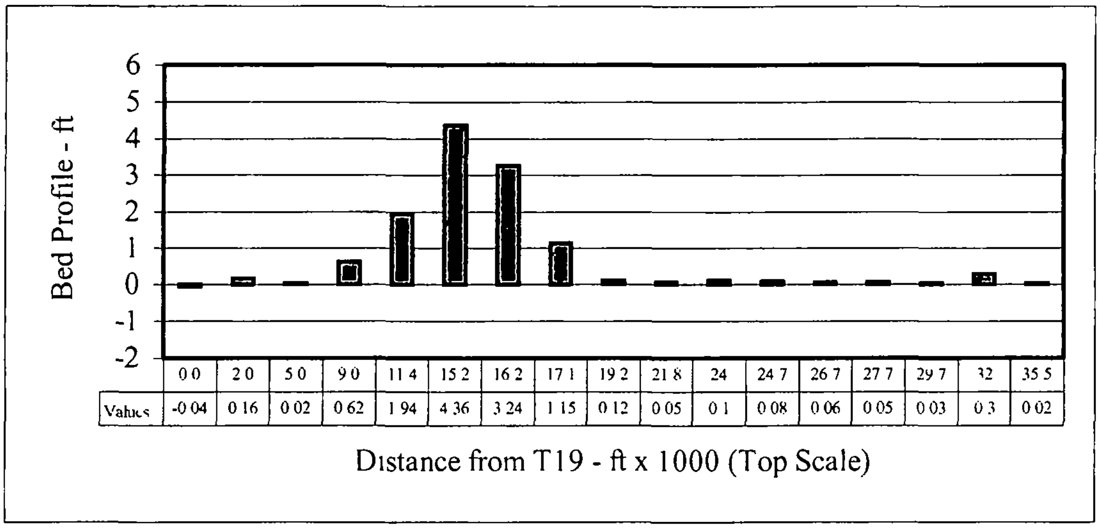


Figure 12 Bed profile just before 1st dredging event

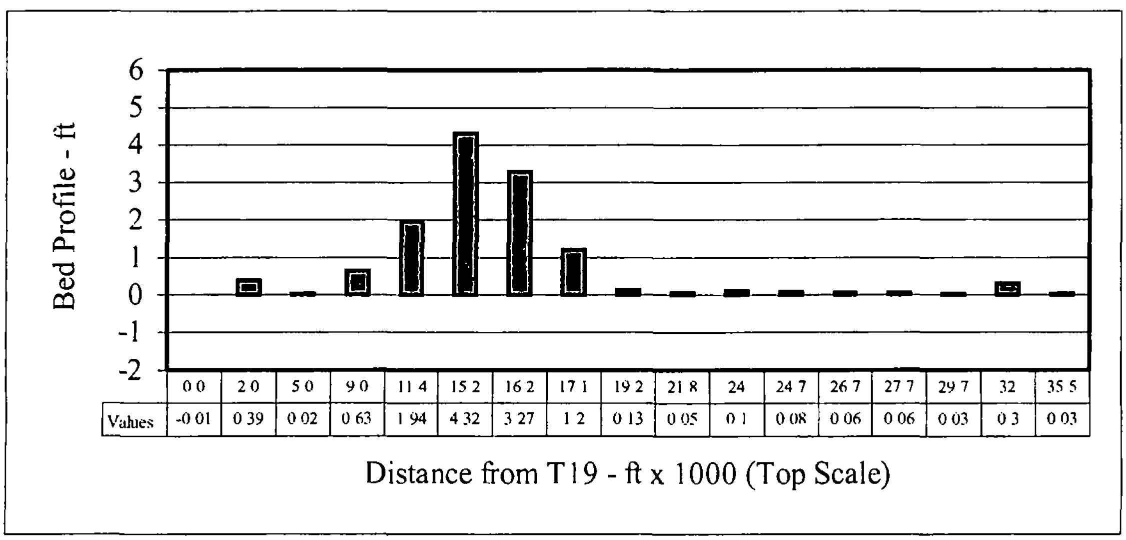
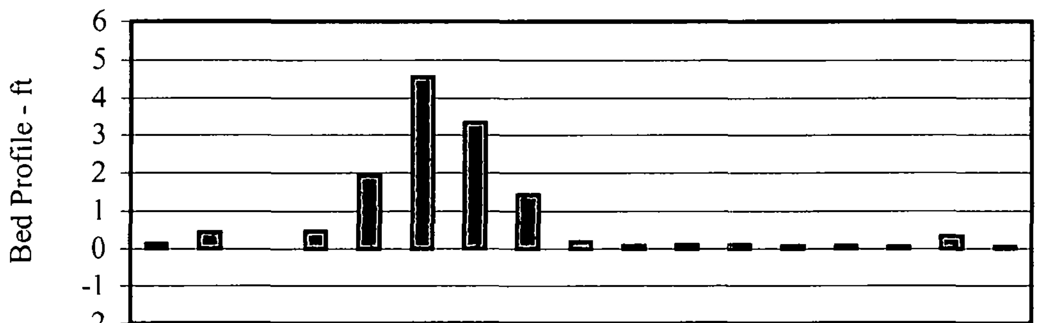


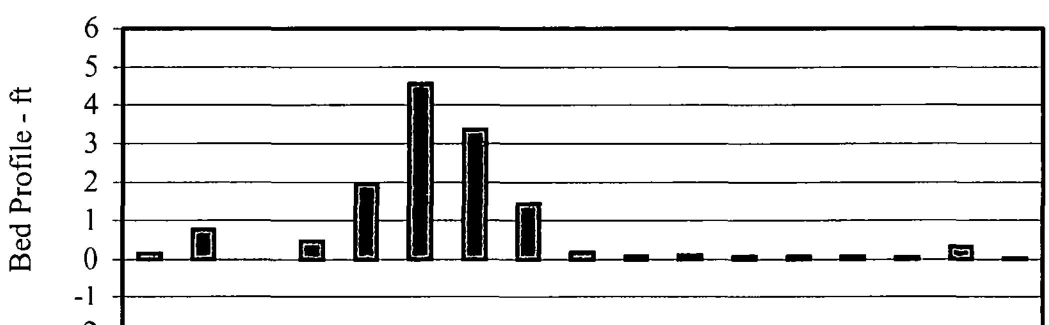
Figure 13 Bed profile after 1st dredging event



	0 0	2 0	5 0	9 0	11 4	15 2	16 2	17 1	19 2	21 8	24	24 7	26 7	27 7	29 7	32	35 5
Values	0 11	0 41	0	0 45	1 93	4 53	3 33	1 43	0 16	0 06	0 1	0 08	0 06	0 06	0 04	0 32	0 03

Distance from T19 - ft x 1000 (Top Scale)

Figure 14 Bed profile just before the 2nd dredging event



	0 0	2 0	5 0	9 0	11 4	15 2	16 2	17 1	19 2	21 8	24	24 7	26 7	27 7	29 7	32	35 5
Values	0 13	0 75	-0 01	0 45	1 94	4 55	3 36	1 43	0 16	0 06	0 1	0 08	0 06	0 06	0 04	0 32	0 03

Distance from T19 - ft x 1000 (Top Scale)

Figure 15 Bed profile after the second dredging event

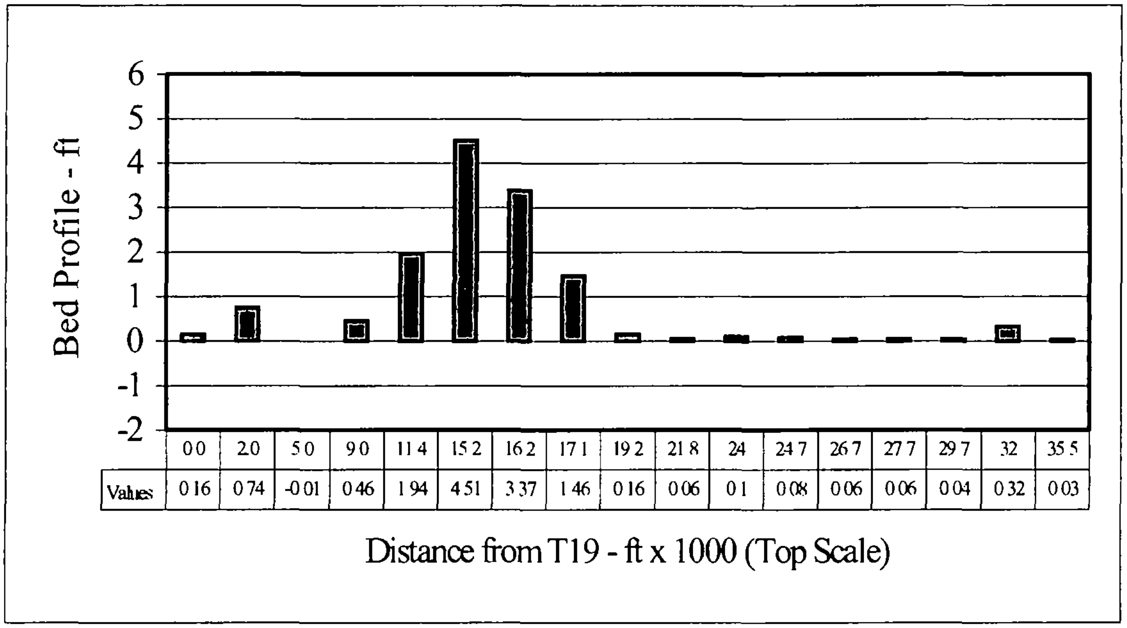


Figure 16 Final bed profile for the seven year, five month simulation

To show the fate of the flushed and dredged sediments as a function of time in the upper reaches of the study area, the model output is presented for sections T19, T18, T17, T16, T15, and Q as a function of time for the seven year, five month run. Figure 17 presents model output data for section T19. The bed profile changes from a peak of 4 0 ft just after flushing to the original bed elevation in approximately one year.

The sediment transport through section T18, the Lay Bridge section, is presented in Figure 18 The flushed sediments accumulate in this section after flushing, but are eroded after approximately 600 days. The dredged sediment accumulations at Lay Bridge are depicted as beginning approximately 1900 days after flushing Sections T16 – T12 show an increasing trend of sediment accumulation over the entire period of record (Figures 20 – 24). This spatial deposition pattern corresponds to the water surface elevation changes of Lake Hartwell (backwater effect) The model indicates that all of the sand sized sediments deposit in the sections above section O, with the bulk of the sediment deposited in sections T15, Q, T12, and P.

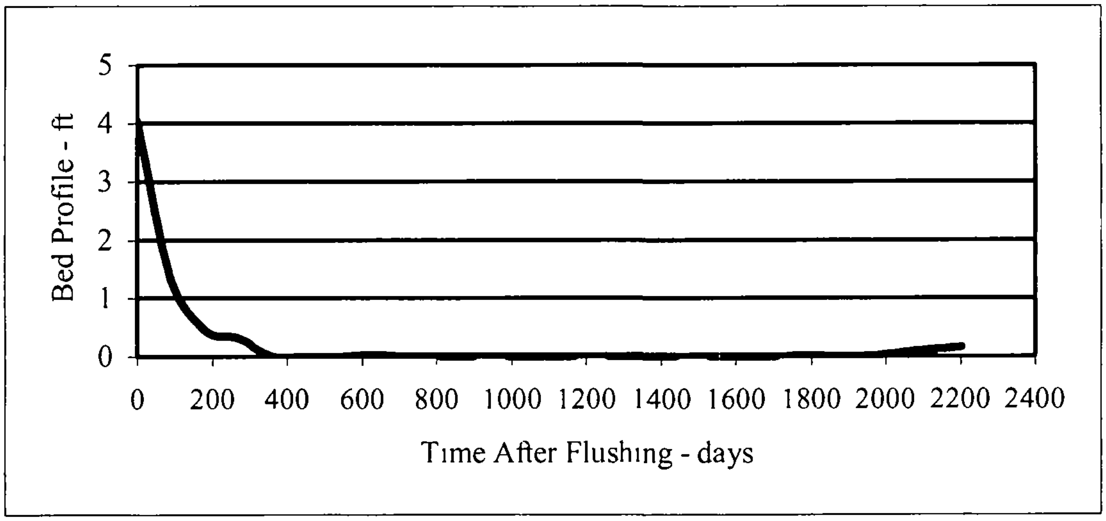


Figure 17 Bed profile time history for section T19

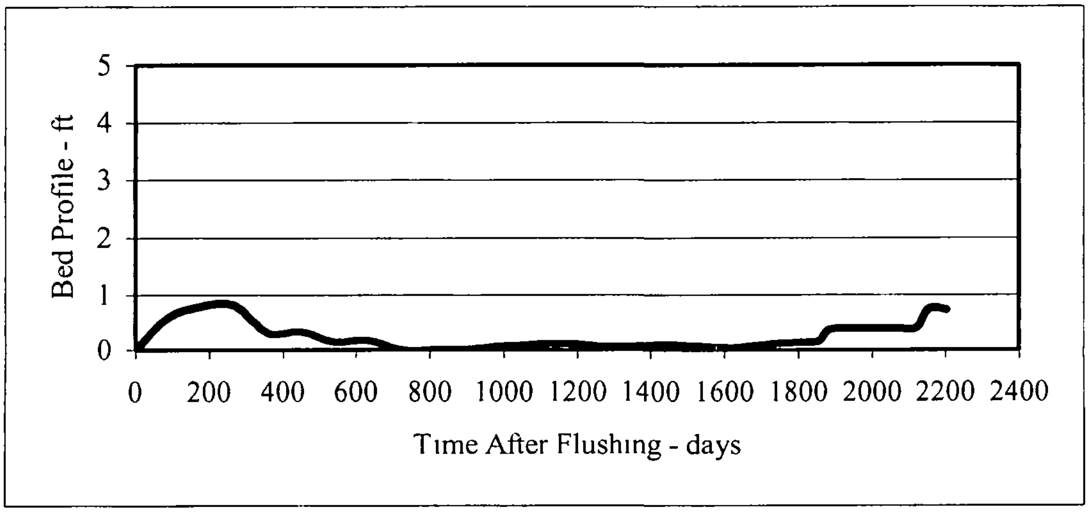


Figure 18 Bed profile time history for section T18

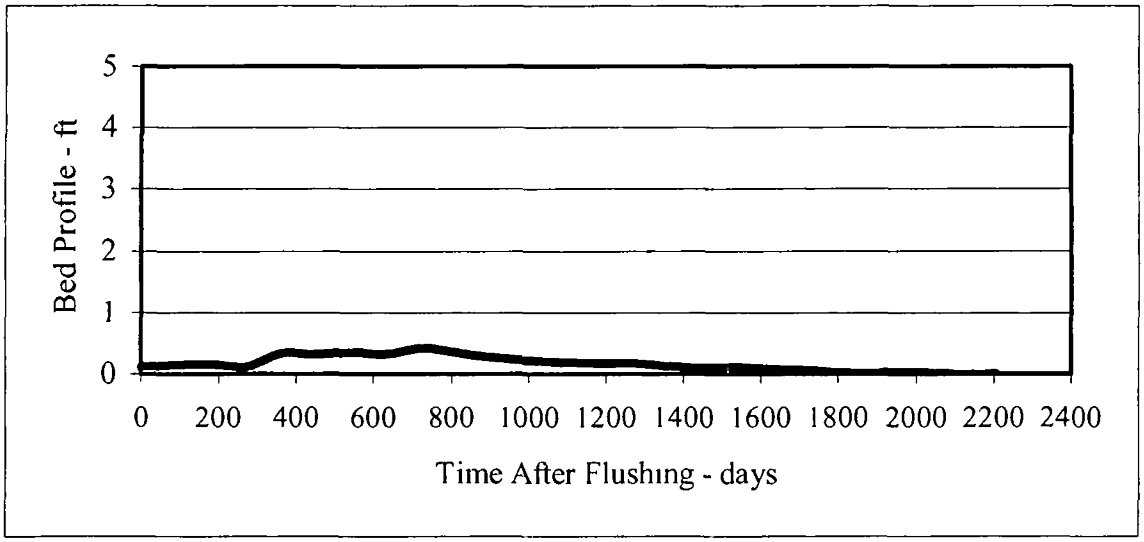


Figure 19 Bed profile time history for section T17

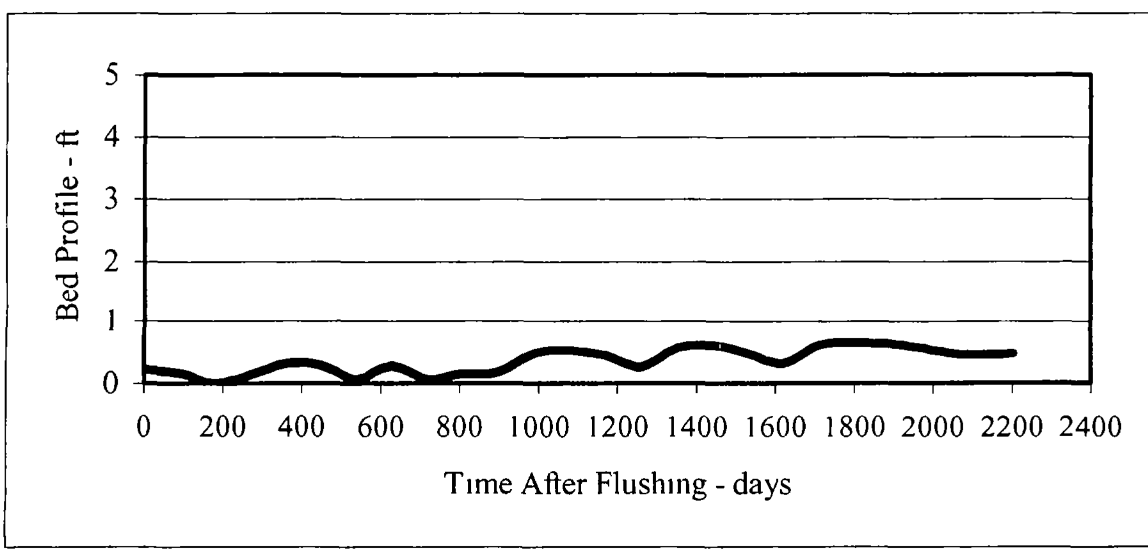


Figure 20 Bed profile time history for section T16

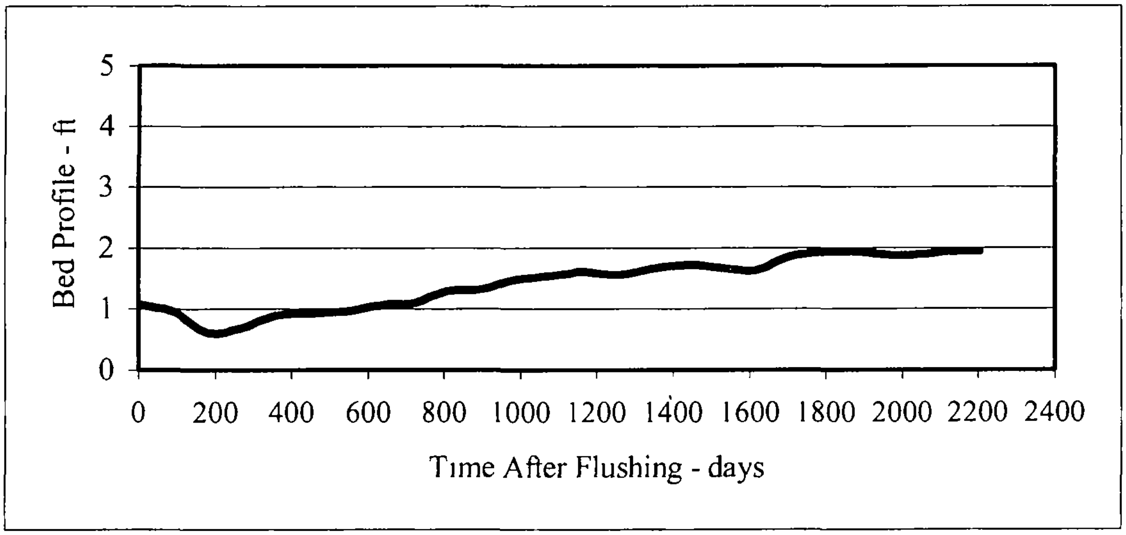


Figure 21 Bed profile time history for section T15

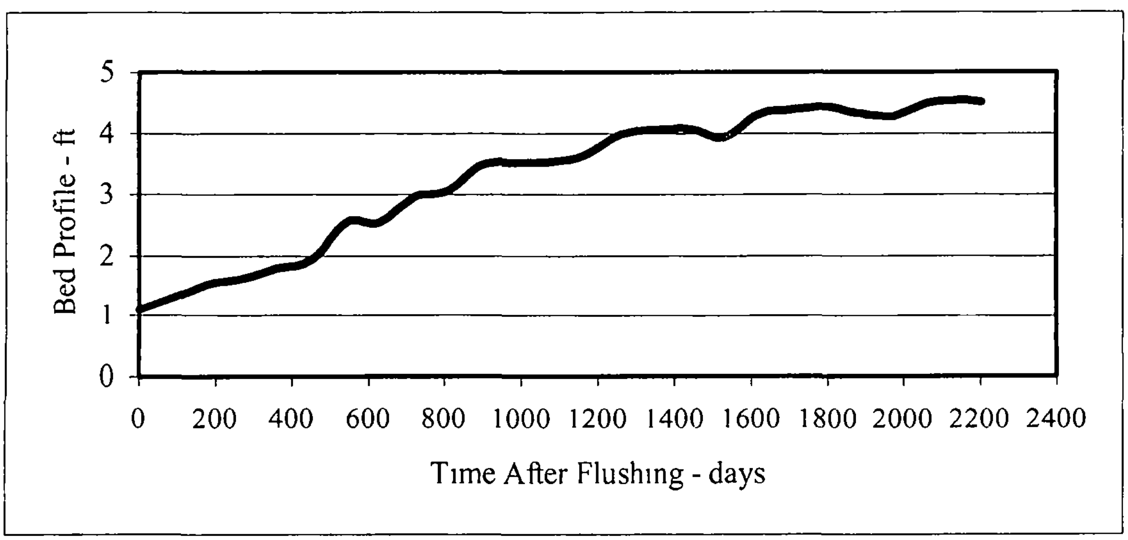


Figure 22 Bed profile time history for section Q

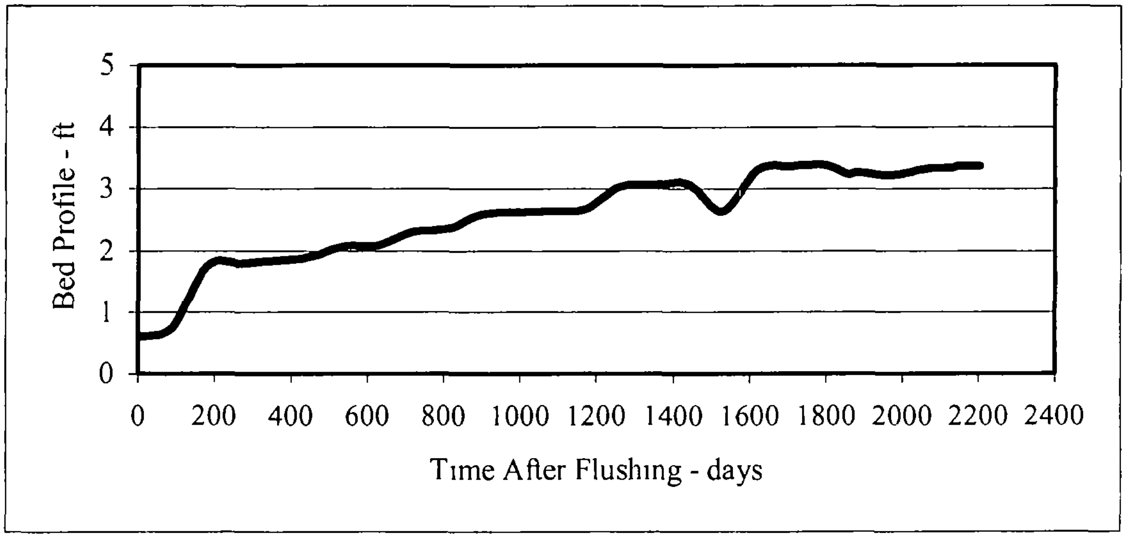


Figure 23 Bed profile time history for section P

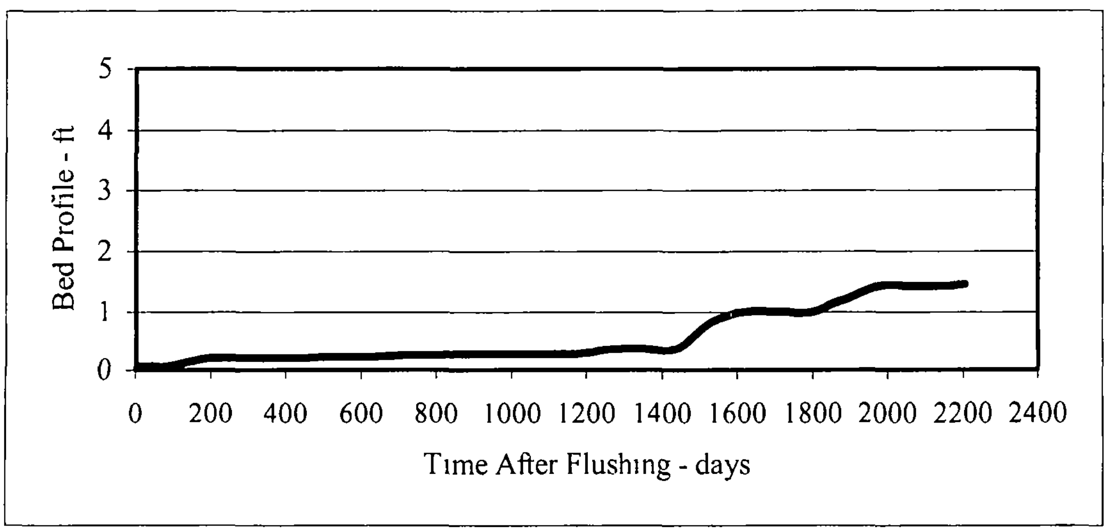


Figure 24 Bed profile time history for section T12

Runs 4 and 5 - evaluation of the impact of varying the flushing discharge from 100 to 500 cubic feet per second

Because the 300 cubic feet per second discharge used in the flushing simulation was very approximate, a higher and lower flushing discharge was run to evaluate the impact on the magnitude of sediment deposition at Woodside II and the fate of the sediments over time These runs were necessary because in reality, the flushing operation is unsteady due to the change in static head in the reservoir with time

Figure 25 presents model output data for section T19 for flushing discharges of 100, 300, and 500 cubic feet per second (cfs). The data indicate that the magnitude of deposition at section T19 changes (3 7 ft to 4.4 ft over the discharge range of 100 - 500 cfs) but the time required for the sediment to migrate downstream remains approximately one year.

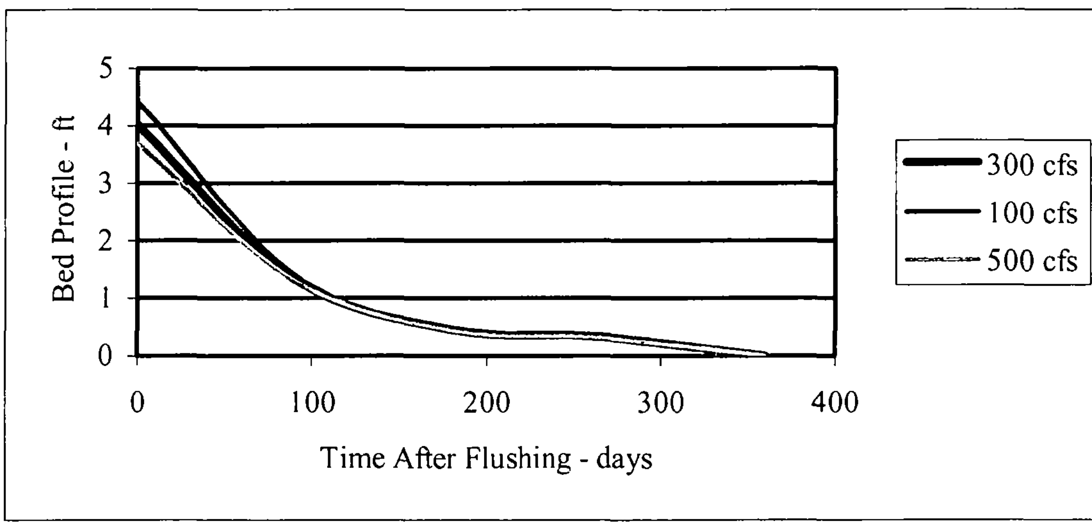
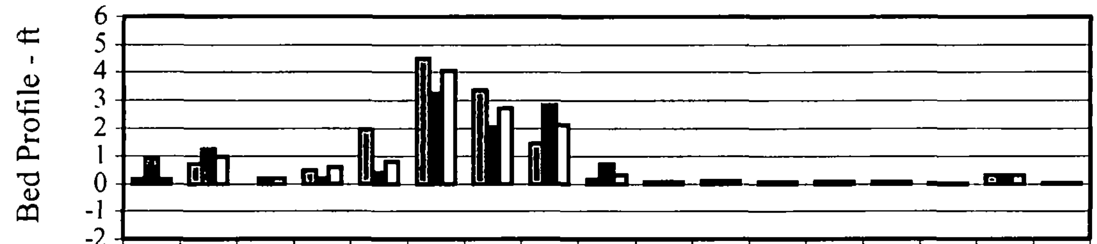


Figure 25 Comparison of varying flushing discharge on bed profile at section T19 (just below Woodside II)

Runs 6 and 7 - evaluation of spatial and quantitative bed profiles for model runs using different sediment transport equations

Model runs 1 – 3 used the Yang equation for sediment transport, as did the Bechtel model runs. The HEC-6 model provides a number of sediment transport relationships that can be incorporated into the model. Bechtel verified the Twelve Mile Creek model with Yangs equation, therefore it was used in the ERDC study Because the ERDC study did not have a direct method of model verification, model run 3 was repeated using two other sediment transport relationships. Madden and Toffaleti – Meyer Peter Muller. Figure 26 presents the bed profiles for the flushing and dredging model run using Yang, Madden, and Toffaleti – Meyer Peter Muller Although the change in bed profile is different for the three relations, they are spatially similar, with the greatest



	0 0	2.0	5 0	9 0	11 4	15 2	16 2	17 1	19 2	21 8	24	24 7	26 7	27 7	29 7	32	35 5
Yang	0 16	0 74	-0 01	0 46	1 94	4 51	3 37	1 46	0 16	0 06	0 1	0 08	0 06	0 06	0 04	0 32	0 03
Madd	0 94	1 26	0 18	0 19	0 38	3 24	2 02	2.85	0 71	0 08	0 11	0 09	0 07	0 06	0 04	0 32	0 03
Toff	0 16	0 98	0 21	0 58	0 81	4 05	2 72	2.09	0 33	0 07	0 1	0 08	0 06	0 06	0 04	0 32	0 03

Distance from T19- ft x 1000 (Top Scale)

Yang Madd Toff

Figure 26 Comparison of impacts of varying sediment transport relationships

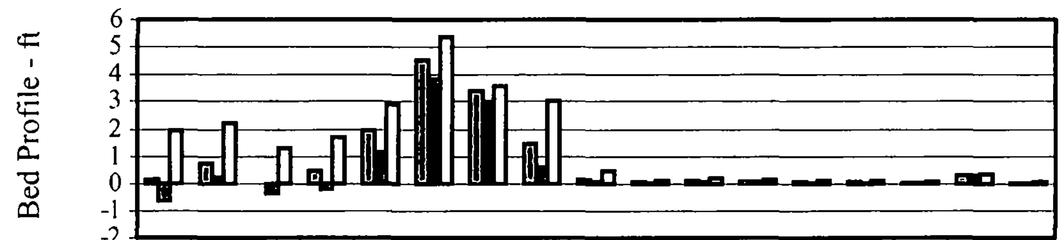
increase in bed elevation occurring in sections Q through T12, much like the bed profiles from earlier runs

Runs 8 and 9 - evaluation of spatial and quantitative bed profiles for increased and decreased sediment loads

For these model runs, the main channel sediment load was varied to evaluate the impact on sediment distribution and overall bed change In model run 5, the sediment load was double of that used in model run 3 Model run 6 had half the sediment load of model run 3 A comparison of the variation in sediment load is presented in Figure 27 for the nominal load (run 3) and the runs with half and double the sediment load. Spatially, the change in bed profile is the same as the previous runs Observations of the upper reaches of Twelve Mile Creek in October of 1999 indicated little or no sediment deposition, with the exception being just below Lay Bridge (section T18) due to dredging operations The run with a doubled sediment load indicated approximately 2.0 ft of sediment deposition in the uppermost section (T19), which appears excessive when compared to observations The run with half the sediment load indicated erosion in the upper reaches

Run 10 - evaluation of spatial and quantitative bed profiles for double the fine sediment load

For this model run, the silt and clay load was doubled from 16 percent to 32 percent of the total load The fractional percent of the coarse sediment size classes was reduced accordingly Dredging and flushing was not included in the analysis Figure 28



	0.0	2.0	5.0	9.0	11.4	15.2	16.2	17.1	19.2	21.8	24	24.7	26.7	27.7	29.7	32	35.5
Nominal	0.16	0.74	-0.01	0.46	1.94	4.51	3.37	1.46	0.16	0.06	0.1	0.08	0.06	0.06	0.04	0.32	0.03
Half	-0.66	0.22	-0.35	-0.2	1.16	3.86	2.99	0.58	0.07	0.04	0.06	0.05	0.04	0.03	0.02	0.3	0.02
Double	1.94	2.2	1.32	1.7	2.9	5.37	3.59	3.01	0.48	0.12	0.2	0.16	0.12	0.11	0.07	0.35	0.05

Distance from T19 - ft x 1000 (Top Scale)

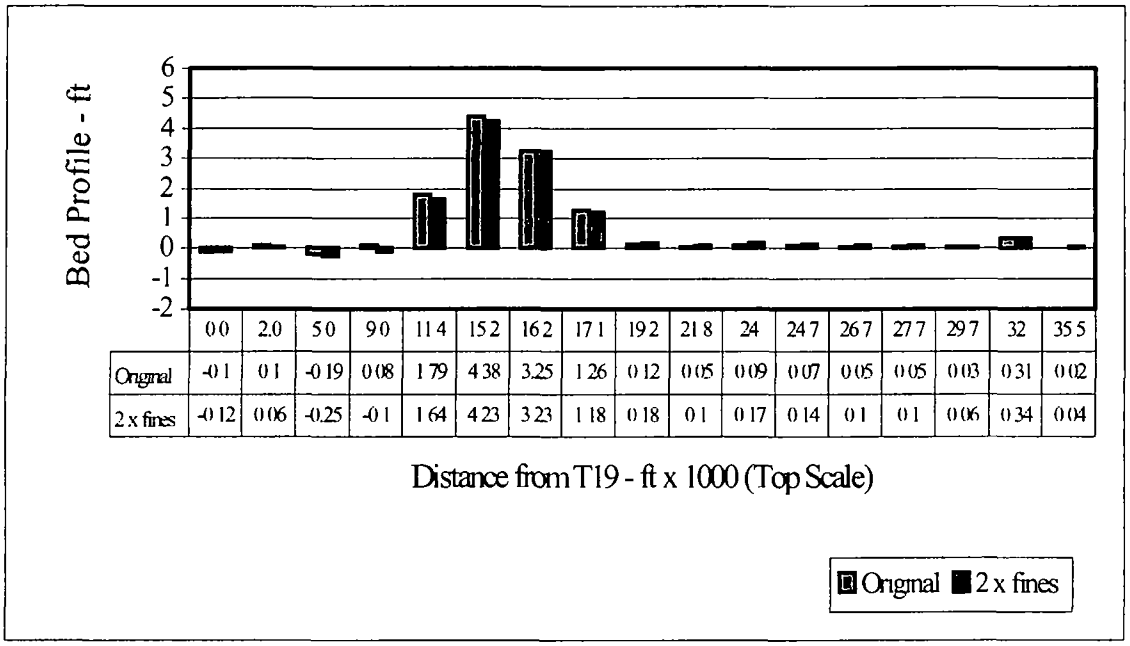
Nominal Half Double

Figure 27 Comparison of model runs with nominal, half, and double the sediment load

presents the final bed profile for the seven year, five month simulation. The lower Twelve Mile Creek sections (sections I – O) indicate that the bed change has approximately doubled with twice the fine sediment load The upper reaches show only a minimal decrease in bed change due to the reduction of sand fraction in the load

Discussion

All of the model runs show the same depositional pattern The model indicates that 100 percent of the sand size sediments transported in the main channel and from the flushing and dredging events are deposited above section N. Almost all of the sediments are deposited between sections T16 and O This area corresponds to the approximate range of fluctuation of the Lake Hartwell water surface elevation. Figure 29 presents the frequency of occurrence of Lake Hartwell stage Figure 30 presents the channel invert elevation for the study section, from section T6 to section T19 For the study time period, the Lake Hartwell stage varied from approximately 653 – 664 NGVD, with a mean elevation of approximately 660 NGVD. At the point where Twelve Mile Creek



	0 0	2.0	5 0	9 0	11 4	15 2	16 2	17 1	19 2	21 8	24	24 7	26 7	27 7	29 7	32	35 5
Original	-0 1	0 1	-0 19	0 08	1 79	4 38	3.25	1 26	0 12	0 05	0 09	0 07	0 05	0 05	0 03	0 31	0 02
2 x fines	-0 12	0 06	-0.25	-0 1	1 64	4 23	3 23	1 18	0 18	0 1	0 17	0 14	0 1	0 1	0 06	0 34	0 04

Figure 28. Comparison of model runs with the original fine sediment percentage and double the fine sediment percentage of the total load

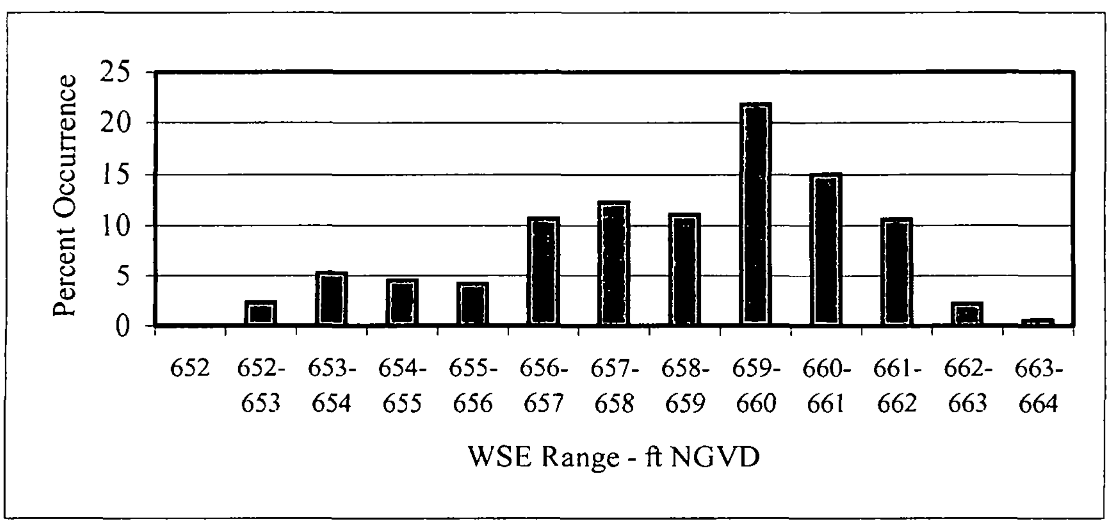


Figure 29. The Lake Hartwell WSE frequency of occurrence

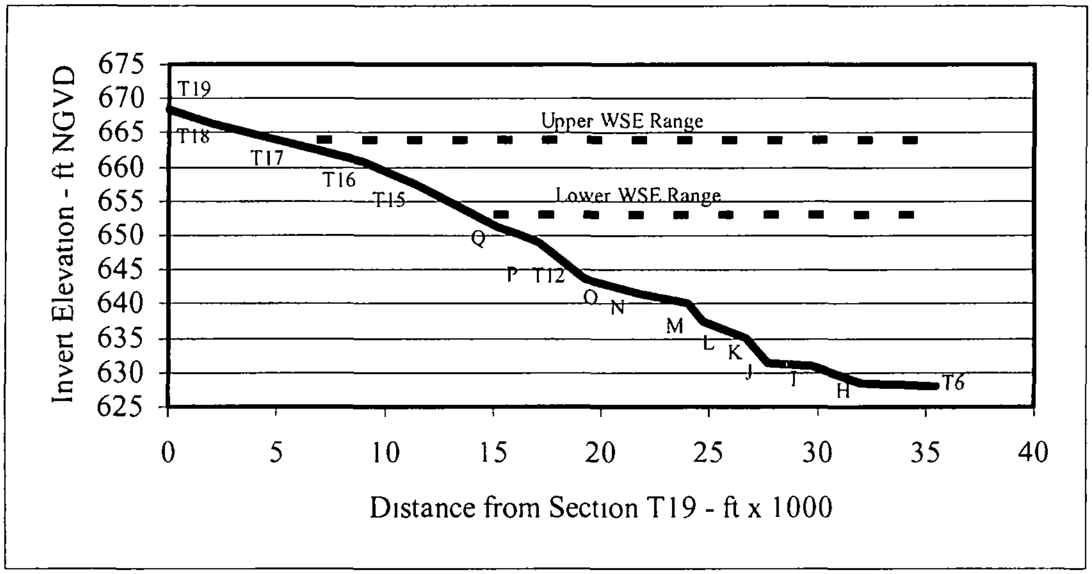


Figure 30 The channel invert elevation from the model upper boundary (section T19) to the lower boundary (section T6)

meets the Lake Hartwell backwater, the reduction in energy slope reduces the flow velocity thus the entrained sediments begin to fall out of suspension The larger particle sizes deposit closer to the backwater interface, whereas the finer sands and silts and clays migrate further downstream before depositing The depositional pattern as predicted by the HEC-6 model clearly shows this trend. All of the sand sized sediments deposit between section T16 and section O, whereas the silts and clays deposit in the lower sections of Twelve Mile Creek

HYDROPOWER RESERVOIR DREDGING STUDY

The ERDC conducted an analysis of the environmental and economic impacts of extending the dredge pipeline from Woodside II to a location approximately five miles downstream. It has been perceived that the past flushing and dredging operations have had a negative impact on the environmental and recreational aspects of the creek

The purpose of by-passing sand around the lower Twelve Mile Creek reach is to eliminate the short-term environmental impacts of disposing of dredged sediments directly into the creek channel Water quality studies conducted during the 1999 dredging event did not indicate a lowering of dissolved oxygen in the lower Twelve Mile Creek channel The only short-term impact on the creek system is a reduction in pool and riffle sequence due to a temporary buildup of sediment just downstream of the dredge discharge pipe The section of creek affected by dredged material sedimentation is a relatively short reach (about 50 yards) just downstream of Lay Bridge Below this point, the degree of sediment deposition in the creek is affected by the water surface elevation of Lake Hartwell When the water surface elevation of Lake Hartwell is high (~ 664 NGVD), the backwater effect will extend up to just below Lay Bridge, where the sand sized sediments will begin to fall out of suspension (Figure 30) Therefore, sedimentation rates in the area below Lay Bridge are controlled more by the stage of Lake Hartwell than short-term dredging events The backwater effect was discussed in detail in the above section.

Two potentially serious impacts can arise from extending the pipeline Access roads will need to be constructed in a rather steep gorge, which extends from Woodside II to below Lay Bridge The construction of these access roads will have an adverse impact on the pristine riparian and streamside vegetation Trees will need to be cut and vegetation cleared along the channel. This will reduce wildlife habitat, and increase the potential for erosion on the steep banks of the creek Additional costs will probably be incurred for erosion protection works to be constructed along the access roads Additionally, the pipeline would probably run through the wetland areas between Lay Bridge and Maw bridge, where some adverse impacts to the wetlands would be inevitable Vegetation along the pipeline route through these wetlands would be cleared, with access roads possibly needed to assemble the pipeline

Bypassing the natural sediment load from the section of Twelve Mile Creek from Woodside II to below Maw bridge could potentially have serious consequences for the long term stability of the system. The creek channel dimensions and planform are directly related to the natural sediment load in the creek Twelve Mile Creek has adjusted over time to the presence of the upstream hydropower reservoirs The reservoirs serve as sediment traps, with periodic releases of sediment into the system through flushing operations Depriving the channel of sediment through bypassing activities could upset the equilibrium of the channel, resulting in degradation of the bed As the bed incises, the banks become over-steepened and bank failures occur This adds additional sediment into the system, which reduces the flow capacity of the stream, resulting in a wider, shallower channel with high turbidity flows In addition to more sediment entering the system, low lying vegetation and trees will enter the channel from the bank failures, further reducing the channel crossection and reducing flow capacity Not only will the aquatic and terrestrial habitat be severely impacted, valued real estate such as streamside docks and access points would be impacted by the increased bank erosion Recreational use of the channel would probably be non-existent

The natural transport of sediments to the Lake Hartwell backwater distributes the sediment evenly across the channel and lake bed Depositing sand from a point source such as a dredge discharge pipe would result in sand mounds which potentially could impact recreational boating travel due to a decrease in water depth and have a permanent impact on the benthic environment. The mounds would be unaffected by flow in the upper channel, and therefore be permanent fixtures in the Lake Hartwell backwater. To prevent the mounding of sediments, a method of evenly distributing the dredged sand would need to be employed, thus potentially resulting in significantly higher dredge operating costs.

The cost analysis indicated that the first year costs associated with extending the dredge pipeline 5 miles will increase the present yearly operations cost by a factor of five for pipeline extension operations with or without a booster pump Subsequent years costs will be less due to existing pipeline and available booster pump The analysis scenario with a booster pump is the most desirable option not only based on cost, but because a booster will insure that the pump will have adequate power for transporting the coarser sand sizes and debris The estimated costs for procuring right-of-way, assembling the pipeline, construction related to laying the pipeline, and the operations associated with moving and positioning the pipe discharge are conservative The complete cost estimate is presented in Appendix A

EVALUATION OF HYDROSUCTION DREDGING TECHNIQUES

A study was conducted by Washington State University in cooperation with the ERDC on the feasibility of using a hydrosuction sediment removal system (HSRS) to bypass sediment from the upstream reservoirs (Woodside I and II) into Twelve Mile creek. The HSRS is a pipeline capable of transporting a water/sediment mixture past a dam using the natural energy represented by the difference in water surface elevations between the upstream and downstream sides of the dam It can be operated in a bypass mode or an active dredging mode The study findings indicate that it is technically feasible to employ the HSRS bypassing or dredging systems to move the annual sediment load in Twelve Mile Creek past Woodside I and II dams with no external source of energy other than a winch and pulley system (in the case of the HSRS dredging) Resulting sediment concentrations in Twelve Mile Creek will be very similar to background levels upstream from the hydropower reservoirs (approximately 120 ppm) Required pipeline diameters vary from 8 to 16 inches depending upon whether the system is operating in a dredging or bypass mode Costs for the pipeline and installation vary from about $160,000 for short dredging systems to about $865,000 for the longer bypassing systems Annual losses to hydropower vary from a low of $3,500 for short dredging systems at both dams to a high value of $11,200 for the longer bypassing system A detailed description of the design, operation and maintenance, and layout of the HSRS systems is found in Appendix B.

CONCLUSIONS

- Analysis of the Bechtel and RMT section survey comparisons revealed that there was too much uncertainty in the data to draw any conclusions on sedimentation rates, particularly in the lower sections of the creek. An exception to this finding was the comparison of surveys at section Q, for which the field data comparison and model predictions are very close

- Analysis of bed samples collected by RMT reveal that the sediment distribution in the upper reaches of Twelve Mile Creek varies from a coarse sand at the Liberty Bridge location to a medium sand in the vicinity of Lay Bridge Sections Q – O primarily contain fine sands, with silts and clays found in the lower reaches of the system

- Although the HEC-6 model used by the ERDC could not be directly verified by all of the pre and post surveys conducted in 1992 and 1999, it is based on a verified model prepared by Bechtel in 1992 The model without the flushing and dredging events predicts a maximum deposition of approximately 4 4 ft at section Q, which is in excellent agreement with the deposition computed from the 1992 – 1999 Q transect survey comparisons (4 4 ft). Additionally, the results of the Corps sediment survey comparison between 1963 and 1973 indicate that the ten year accumulation of sediment between the reaches of T16 and T12 average approximately 3 0 ft. The model predicted an average sediment deposition of approximately 2 7 ft over 7 4 years, which extrapolates to 3 6 ft over 10 years

- The model results indicate that all of the sand sized sediments (> 0.075 mm) will be deposited above section O, with the majority of the sands deposited in sections T15 – T12

- The model results indicate that the bed elevation just below Woodside II increased to approximately 4.0 ft just after flushing was completed The model indicates that the deposited sediments due to flushing migrated to downstream reaches in approximately 1 year The two dredging operations resulted in sediment deposits of 0.41 and 0.75 feet respectively at the Lay Bridge section (just below T18). The model results indicate that the sediment deposition resulting from dredging has not been eroded from the area as of September 30, 1999 (last record of the simulation).

- Sensitivity analyses conducted to evaluate the impact of using different sediment transport relationships in the HEC-6 model indicate that the spatial distribution of sediment remains essentially the same, with some difference on the magnitude of sediment accumulations within the sections.

- Increasing the fine sediment fraction (clay and silt) of the incoming sediment load results in a proportional increase in sediment deposition in the lower reaches of Twelve Mile Creek (sections N – H), indicating that sediment deposition in the lower reaches of Twelve Mile Creek (the backwater of Lake Hartwell) is totally dependent on the fine sediment load and not the sand load in the system

- The spatial and quantitative distribution of sediment in Twelve Mile Creek is dependent on the backwater effect of Lake Hartwell The fluctuations of Lake Hartwell stage will dictate where the sediments transported in the channel will be re-distributed

- Disposal of dredged material just below Lay Bridge results in a short-term adverse impact on channel habitat Pool and riffle sequences will temporarily be impacted due to sediment accumulations approximately 50 yards below Lay Bridge The backwater effect of Lake Hartwell controls the quantity and distribution of sediments deposited in reaches below Lay Bridge.

- Bypassing the sediment below the gorge area of Twelve Mile Creek may potentially have a de-stabilizing effect on the channel, resulting in possible bed and bank erosion

- Extending the dredge discharge pipeline 5 miles downstream from Lay Bridge will increase the first year operations cost by a factor of 5. Subsequent years costs will increase due to increased maintenance

- It is technically feasible to bypass sediments from the Woodside I and II reservoirs using hydrosuction sediment removal systems (HSRS) Construction costs range from $160,000 for short dredging systems to $850,000 for longer bypassing systems Yearly costs to hydropower range from $3,500 to $11,200 for the dredging and bypassing systems respectively.

RECOMMENDATIONS

The HEC-6 modeling efforts for both the Bechtel and ERDC studies indicate that the sand sized sediments transported below Woodside II will be deposited in areas of Twelve Mile Creek that correspond to the water surface elevation range of Lake Hartwell (roughly from section T17 to Q) The model runs predict that 100 percent of the sands will deposit in the "dogleg" area of the creek (sections T16 - O), with only fine sediments (silts and clays) transported below section N. Therefore, to determine the fine sediment load entering the lower reaches of Twelve Mile Creek, suspended sediment samples should be obtained from a location such as Maw Bridge Initially, discharge measurements need to be taken along with the suspended sediment samples The initial set of discharge measurements should be compared to the Liberty Bridge discharge, and a statistical relationship developed for predicting discharge based on the Liberty gauge data

The Bechtel and ERDC studies were based on a sediment rating curve developed from verification and observation The rating curve is applicable for sediment loads discharged below Woodside II It is strongly recommended that the Twelve Mile Creek system be evaluated in its entirety by establishing a study reach from Liberty Bridge to section T6 in Lake Hartwell This reach will include the three reservoirs. The sediment rating curve will be based on channel geometry, roughness, and bed gradation at Liberty Bridge. Additionally, a number of channel surveys need to be conducted between Woodside II and Liberty Bridge for model continuity. The reservoirs will need to be surveyed as well. This will provide a model that encompasses the entire system, therefore providing analysis capability at any point along the study reach With this capability, the impacts of sand bypassing at any of the three reservoirs can be evaluated from the source to the end of the study reach (Lake Hartwell). With the present models, the impacts on the channel above Woodside II are unknown

It is not recommended that the current dredge pipeline be extended for discharging sand directly into the backwater of Lake Hartwell. The risk of adverse impacts on the lower Twelve Mile Creek channel (along with associated wetlands and riparian areas) far outweighs the temporary short-term shoaling problems associated with depositing sands within the creek channel. Field inspections of the Lay Bridge area after dredging operations ceased indicated that the pool and riffle areas that filled in with sediment during dredging operations were beginning to re-appear It is anticipated that high flows in the winter and spring will scour out the remaining sediments and return the affected areas to pre-dredge conditions.

The HSRS study provided the data necessary for design and implementation of a prototype system Concepts were presented for collecting and transporting the sediments from the hydropower reservoirs. The actual design, fabrication, and testing of these systems, particularly the sediment collection design, was not addressed. It is recommended that a pilot scale HSRS system be tested and evaluated before a full-scale HSRS system be employed on the hydropower reservoirs Although the HSRS concept is technically feasible, the costs and technical difficulties involved with actual fabrication and implementation are relatively unknown at this time

APPENDIX A

Evaluation of the Economic and Environmental Impacts Associated with a Five Mile Dredge Discharge Pipeline

ECONOMIC AND ENVIRONMENTAL IMPACTS FOR A FIVE MILE PIPELINE EXTENSION

TWELVE MILE CREEK / LAKE HARTWELL REMEDIATION DREDGING

BACKGROUND

Portions of Twelve Mile Creek and Lake Hartwell contain PCB contamination resulting from the operation of a capacitor manufacturing facility located in the upstream watershed of Twelve Mile Creek. In June 1994, the EPA issued a Record of Decision (ROD) for this site, referred to as the Sangamo OU2 Site This ROD addressed the sediment, surface water, and sediment transport pathways from land based source areas adjacent to the capacitor manufacturing facility

To address the sediment contamination problem in Twelve Mile Creek and Lake Hartwell, the EPA's selected remedy is to use the natural sedimentation processes of Twelve Mile Creek to deliver sediment to the contaminated areas, thus providing a clean sediment cap on top of the contaminants to prevent further resuspension and transport of PCB's through the creek and lake system

Two small hydropower reservoirs are found on Twelve Mile Creek, Woodside I and Woodside II. The reservoirs act as sediment traps, and thus must be periodically flushed of sediment to have sufficient capacity for power generation. Historically, the sediment was flushed downstream through sluice gates when sediment accumulations began to interfere with power generation This practice was discontinued in September 1993 due to adverse impacts in the downstream water quality

In mid-1998, the EPA, along with Schlumberger (responsible party for remediation) developed a more comprehensive sediment management plan for the hydropower reservoirs which involved dredging the sediment with a hydraulic dredge and depositing it downstream of the reservoirs The dredged sediment would then be transported as suspended and bed load through the Twelve Mile Creek system and be deposited within the backwater areas of Lake Hartwell, thus providing a protective cap over the PCB contaminated sediments

In the fall of 1998, the dredging operations began in Woodside I and II. Due to relatively low water during the fall, the dredged sediment accumulated in the lower Twelve Mile Creek channel The dredged sediment accumulation within the Twelve Mile Creek channel was a temporary impact due to low water, with the material transported to the Lake Hartwell backwater during high flows in the winter and spring Regardless, local citizens expressed concerns that the additional sediment in the channel would have a short-term adverse impact on water quality, fish resources, and recreational uses of the creek

In response to the citizens concerns, the EPA initiated efforts to study the sediment transport characteristics of Twelve Mile Creek, and to investigate alternative methods for transporting the sediments from the hydropower reservoirs to the Lake Hartwell backwater One of the alternative methods was to pump the dredged sediments five miles below the reservoir directly to Lake Hartwell, thus bypassing the Twelve Mile Creek channel reach from the reservoirs to Maw Bridge. This would involve laying a 5 mile pipeline from Woodside II to the area of Lake Hartwell below Maw Bridge This report documents the estimated costs for extending the pipeline and purchasing and maintaining a pump booster station, if required

PROBLEM

Discharging the dredged sediments directly into Twelve Mile Creek, particularly at low water, presents a short term impact on the system Bed samples taken from the reservoirs and from the bed adjacent to the dredge discharge indicate a medium to coarse sand containing very little fine sediment. The short term impacts include sand shoals, which may impede recreational activities such as canoeing, and the temporary filling in of pool and riffle areas, which are recognized as good habitat for aquatic organisms Extending the dredge pipeline 5 miles to areas below Maw Bridge will bypass the upper Twelve Mile Creek channel and deliver the sediments directly to contaminated areas in Lake Hartwell Although this seems to be an acceptable solution, extending the pipeline through a remote and environmentally sensitive area has a number of drawbacks, particularly in the areas of cost and impact on the environment. Three cost scenarios are presented below They include 1) the present dredging operation 2) the present dredging operation with a 5 mile pipeline extension and 3) the present dredging operation with a 5 mile pipeline extension and a booster pump to maintain production

SCENARIO 1 - PRESENT DREDGING OPERATION

Presently, a hydraulic cutterhead dredge with an 8.0 inch pipeline accomplishes the dredging in the hydropower reservoirs A 300 horsepower motor powers the on-board centrifugal pump. The pipeline length is approximately 150 ft, which is just enough to discharge the material below the reservoirs The nominal flow rate through the pipeline is 2000 gallons per minute The average volume of sediment removed yearly is 14,000 cubic yards. The hourly operations cost is \$195 / hr, with a total yearly cost of \$200,000 / yr The total operations time at both reservoirs was 700 hours

The total project cost is based on the operations cost and the mobilization and de-mobilization costs of the project The operations cost are for dredge operations plus any incidental maintenance required during the conduct of the project For the Twelve Mile Creek project, this is computed as an hourly cost at the rate of \$195 / hr The mobilization and de-mobilization costs are incurred from the delivery and pick up of the dredge, lowering and removing the dredge into the reservoir from a steep bank, and laying and maintaining the pipeline

Operations Costs

The operations cost is based on the total time spent dredging Therefore, the operations cost for the present dredge operation is computed as 700 hr / yr x $195 / hr = $136,500 / yr

Mobilization and De-mobilization Costs

The mobilization and de-mobilization costs are the difference between the total cost and operations cost· $200,000 / yr - $136,500 / yr = $63,500 / yr The costs for the present dredging operation are tabulated in Table 1

Table 1 Summary of Present Dredging Operations Costs

Total / Yr	Dredging Time	Mob / De mob
$200,000	$136,500	$63,500

SCENARIO 2 - PRESENT DREDGING OPERATION WITH A 5-MILE PIPELINE EXTENSION

When the additional 5 miles of pipeline are added to the system, more power is required by the pump to overcome the additional frictional resistance of the longer pipeline In this case, the dredge pump is assisted by the drop in elevation over the 5 mile pipe length. The drop in elevation across Woodside II is approximately 30 feet, with an additional 20 feet drop in elevation from Woodside II to the pipeline discharge location 5 miles downstream of the reservoir Therefore, the dredge pump has an additional 50 feet of pressure head for overcoming the friction losses in the line Dredge production analysis for the 8.0 inch dredge indicate that the dredge can maintain a production rate of about 9 cubic yards per hour without the assistance of a booster pump when operating in a medium sand

The costs associated with extending the pipeline 5 miles are the cost of the pipeline, the costs associated with constructing the pipeline, the additional time required to dredge the 14,000 cubic yards of sand due to the lower production rate, the cost to procure right of way for the pipeline, construct access roads to the pipeline, and general maintenance of the pipeline Each cost will be considered below

Pipeline Cost

The cost of 8 0 inch ID polyethylene plastic pipe is $11 62 / ft, with a total cost for 5 miles of $306,768 Additional costs for handling and shipping increase the total cost to $327,000

Additional Time Required at Lower Production Rate

The present dredge operation production rate is based on the time required for dredging and the total volume of material removed The time actually spent dredging is a function of the total time For the present dredging operation, it is assumed that of the 700 hours on site, only 560 hours are spent actually dredging (20 percent down time, maintenance, etc) This results in a dredge production rate of 14,000 cubic yards / 560 hours = 25 cubic yards per hour As mentioned before, the reduced production rate due to the pipeline extension is 9.0 cubic yards per hour Therefore, the time required to remove the 14,000 cubic yards with the pipeline extension is (25 cy / hr / 9 cy / hr) x 700 hr = 1944 hours, with the cost being 1944 hr x $195 / hr = $379,080

Costs to Procure Right of Way, Construction of Pipeline, and Access Roads

All sections of the pipeline must be accessible for construction and maintenance purposes Right-of-way must be procured from landowners or publicly held lands Because Twelve Mile Creek is not navigable, it will be necessary to construct access roads to the pipeline Additionally, the pipeline is welded together with special equipment that must be brought to the site The total cost of these functions is conservatively estimated to be equivalent to the operations cost, or approximately $379,080

Mobilization and De-mobilization of the Dredge

These costs would be the same as for the present dredge operation, approximately $63,500.

Total Cost of the Present Dredging Operation With the Extended Pipeline

The total estimated cost of scenario 2 would be $1,148,660 the first year, with subsequent yearly operations costs of $482,580 The costs associated with Scenario 2 are tabulated in Table 2

Table 2 Summary of Present Dredging Operations Costs With an Extended Pipeline

Total / Yr	Pipeline	Dredging Time	Pipeline Install / Maint	Mob / De mob
*$1,148,660	$327,000	$379,080	$379,080	$63,500
**$482,580	NA	$379,080	$40,000	$63,500

* - First year cost

** - Subsequent yearly cost

SCENARIO 3 - PRESENT DREDGING OPERATION WITH THE EXTENDED PIPELINE AND A BOOSTER PUMP TO MAINTAIN PRESENT PRODUCTION

The additional of a booster pump station will allow the dredge to maintain the current production rate with the extended pipeline. Therefore, the operations costs based on dredging time will be the same as Scenario 1 The pipeline costs, assembly, construction, right-of-way acquisition, and mobilization / de-mobilization will be the same as in Scenario 2. The additional cost for Scenario 3 is the purchase price of the booster, the operations and maintenance cost for the booster station, and the mobilization and de-mobilization cost of the booster The costs are presented below

Pipeline Costs

The pipeline costs are the same as for Scenario 2, $327,000.

Operations Costs - Dredging Time

These costs are the same as for Scenario 1, $136,000.

Operations Costs - Purchase and Operation and Maintenance of Booster

The cost of a 300 horsepower booster pump with controls is estimated to be $100,000 The cost of operating and maintaining the pump is estimated to be $40,000 / yr

Costs to Procure Right of Way, Construction of Pipeline, and Access Roads

These costs are the same as for Scenario 2, $379,080

Mobilization and De-Mobilization of the Dredge and Booster Pump

These costs are estimated to be approximately $110,000

Total Cost With Pipeline Extension and Booster Pump

The total cost of Scenario 3 would be $1,092,080 the first year, with a subsequent yearly operation cost of $326,000. The costs for Scenario 3 are found in Table 3.

Table 3. Summary of Present Dredging Operations Costs With an Extended Pipeline and Booster Pump Station

Total / Yr	Booster	Pipeline	Dredging Time	Pipeline Install / Maint	Mob / De mob
*$1,092,080	$140,000	$327,000	$136,000	$379,080	$110,000
**$326,000	$40,000	NA	$136,000	$40,000	$110,000

* - First years cost

** - Subsequent yearly cost

ENVIRONMENTAL CONSIDERATIONS

From purely a cost viewpoint, extending the pipeline five miles is a feasible, yet costly, alternative Because the sole purpose of extending the pipeline is to protect the aquatic and terrestrial habitat associated with the Twelve Mile Creek channel between Woodside 2 and Maw Bridge, the environmental impacts of such a pipeline must be considered

Two potentially serious impacts can arise from extending the pipeline. Access roads will need to be constructed in a rather steep gorge, which extends from Woodside 2 to below Lay Bridge The construction of these access roads will have an adverse impact on the pristine riparian and streamside vegetation Trees will need to be cut and vegetation cleared along the channel This will reduce wildlife habitat, and increase the potential for erosion on the steep banks of the creek Additional costs will probably be incurred for erosion protection works to be constructed along the access roads Additionally, the pipeline would probably run through the wetland areas between Lay Bridge and Maw bridge, where some adverse impacts to the wetlands would be inevitable. Vegetation along the pipeline route through these wetlands would be cleared, with access roads possibly needed to assemble the pipeline.

Bypassing the natural sediment load from the section of Twelve Mile Creek from Woodside 2 to below Maw bridge could potentially have serious consequences for the long term stability of the system. The creek channel dimensions and planform are directly related to the natural sediment load in the creek Twelve mile creek has adjusted over time to the presence of the upstream hydropower reservoirs The reservoirs serve as sediment traps, with periodic releases of sediment into the system through flushing operations Depriving the channel of sediment through bypassing activities could upset the equilibrium of the channel, resulting in degradation of the bed As the bed incises, the banks become over-steepened and bank failures occur This adds additional sediment into the system, which reduces the flow capacity of the stream, resulting in a wider, shallower channel with high turbidity flows. In addition to more sediment entering the system, low lying vegetation and trees will enter the channel from the bank failures, further reducing the channel crossection and reducing flow capacity Not only will the aquatic and terrestrial habitat be severely impacted, valued real estate such as streamside docks and access points would be impacted by the increased bank erosion Recreational use of the channel would probably be non-existent

SUMMARY

The cost scenario analysis indicates that the first year costs associated with extending the dredge pipeline 5 miles will increase the present yearly operations cost by a factor of 5 for scenarios with and without a booster pump Subsequent years costs will be less due to the existing pipeline and available booster pump ($482,000 / yr and $326,000 / yr for Scenarios 2 and 3 respectively) Scenario 3 with the booster pump is the most desirable option not only because of the cost, but because a booster will insure that the pump will have adequate power for transporting the coarser sand sizes and debris. The estimated costs associated with procuring right-of-way, assembling the pipeline, and construction related to laying the pipeline are conservative, and could be much higher

Although it is technically feasible to extend the pipeline, the probability of severe adverse impacts to the channel, wetland, and riparian environment is high. The impact of the present dredging operation on the Twelve Mile Creek channel is very temporary, with the accumulated sediments expected to leave the channel when the winter and spring rains arrive. The pool and riffle sequences that are valuable habitat features in the creek will be restored before any long-term adverse impacts occur

APPENDIX B

Evaluation of the Hydrosuction Dredging Technique as a Cost Effective Alternative to Hydraulic Dredging

HYDROSUCTION SEDIMENT REMOVAL SYSTEMS FOR WOODSIDE I AND WOODSIDE II DAMS - FINAL REPORT

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PURPOSE

The purpose of this report is to describe Hydrosuction Sediment Removal System (HSRS) alternatives for Woodside I and Woodside II dams (WSI and WSII, respectively) An HSRS is a pipeline system capable of transporting a water/sediment mixture past a dam using the natural energy represented by the difference in water surface elevations between the upstream and downstream sides of the dam. This report describes the required pipe sizes to maintain a sediment balance across both dams, cost estimates for the pipeline materials/installation, conceptual layouts for the alternatives discussed, and maintenance issues No cost estimates are included for structural modification to the low-level outlets or installation of the dredging system alternative; these are either being done by another consultant (RMT, Inc) or will be provided for a more detailed project plan.

SUMMARY

It is technically feasible to employ HSRS bypassing or dredging systems to move the annual sediment load past Woodside I and Woodside II dams with no external source of energy other than a winch and pulley system in the case of HSRS dredging. Resulting sediment concentrations in TMC will be very similar to background levels upstream from the projects Required pipeline diameters vary from 8 to 16 inches depending upon the alternative. Costs for pipeline and installation vary from about $160,000 for short dredging systems to about $865,000 for the longer bypassing systems. Annual losses to hydropower vary from a low of $3,500 for short dredging systems at both dams to a high value of $11,200 for the longer bypassing systems

HYDROSUCTION SEDIMENT REMOVAL SYSTEMS

An HSRS consists of a pipeline and appurtenant valves to control flow The pipeline entrance is placed upstream at a location where sediment capture or removal is desired in a stream channel or reservoir. The pipeline extends downstream either over the dam or through low-level outlets to a location within the channel downstream from the dam. Water and sediment are driven through the pipeline by the energy represented by the elevation difference between the upstream and downstream water levels (Hotchkiss and Huang, 1995).

BASIS FOR DESIGN FOR WSI AND WSII DAMS

The required pipe size for an HSRS systems depends upon pipeline length, sediment load and size of grains, and available energy to drive the water/sediment mixture through the pipe Available energy is represented by the difference between the water surface elevations above the pipe inlet and outlet

Sediment Load and Size Distribution

Sediment load The HSRS alternatives were designed to move the average annual sediment load over a one-year period That is, all of the incoming sediment to WSI and WSII dams in an average year will be moved past the respective dams in one year's time. The mean annual sediment load was determined in a two-step process. It was first necessary to determine the historic pattern of flows on Twelvemile Creek (TMC) near the dams. This was done by adjusting the long-term discharge record of the TMC Liberty stream gage located upstream from the dams (Appendix). The South Carolina District of the U S. Geological Survey provided flow duration data for the gage based on the long-term record (personal communication, 1999) These flows were increased by 20% based on the ratio of drainage areas at the Liberty gage and at the dams. Sediment loads for each of the discharges in the historic record were read from the recent sediment rating curve developed for a computer simulation of sediment transport in TMC (Appendix F, May 1993). The resulting mean annual sediment load so computed is 170 Tons/Day. The HSRS alternatives were designed to pass 200 Tons/Day

Sediment sizes The sediments in TMC vary along its length The sediments found in the flowing portion of the Creek are coarser than those found in the depositional areas of the downstream Lake Hartwell The sediment sizes presumed to be transported through the HSRS pipelines are from a location knows as "BS-3 " This location, designated as bed sample 3, was taken downstream from the Liberty stream gage on TMC (Parker and White, 1999) The grain size distribution at BS-3 is slightly finer that those found in either the WSI or WSII impoundments The impounded sediment presently in the reservoirs represents the coarser portion of the inflowing sediment load; finer material is flushed downstream Thus for long term stream stability, the grain size distribution of the flowing portion of TMC is more representative than that found in the impoundments The median sediment size of the BS-3 sample was 0.70 mm

Alternatives Analyzed

Six alternatives were analyzed for the two dams; two for WSI and four for WSII. All alternatives are summarized in Table 1 The bypass alternatives assume the pipeline entrance is located upstream from the dam at a point near where the reservoir begins Thus, sediment would be intercepted before depositing in the reservoir, and would be passed downstream Bypass pipeline systems are longer than dredge systems A dredge system collects sediments near the face of the dam after the sediments have been deposited and moved slowly through the reservoir along the bed towards the dam. The WSII alternatives include two different outlet locations one located upstream from the Lay bridge, and another located farther downstream past the bridge and past a sensitive TMC reach characterized by a rocky bed and whitewater rapids.

Assumptions for HSRS analyses

The assumptions and parameters used in the HSRS analysis are summarized in Table 2 The analysis is based on the concepts and equations found in Hotchkiss and Huang (1995), with two corrections The first correction changes the exponent modifying the pipeline velocity (Equation 11) in the paper from the quantity 1/(2(m-1) to 1/(2m-1) The second correction is to an exponent in Equation 12, which describes sediment transport in the pipeline Instead of reading (1-2m)/(2m-1), the exponent should read (1+2m)/(2m-1).

Table 1. Definition of Alternatives

Alternative	Available head, ft	Pipeline length, feet		
		Upstream	Downstream	Total
Woodside I Dam bypass (WSIB)	38.2	1000	800	1800
Woodside I Dam dredge (WSID)	38 2	50	800	850
Woodside II Dam bypass to Lay bridge (WSIIBB)	40 4	1000	1600	2600
Woodside II Dam bypass past Lay bridge downstream (WSIIBF)	42 05	1000	2700	3700
Woodside II Dam dredge and pass to Lay bridge downstream (WSIIDB)	40 4	50	1600	1650
Woodside II Dam dredge and pass past Lay bridge (WSIIDF)	42 05	50	2700	2750

Table 2 Assumptions for HSRS Bypassing Systems

Parameter	Value	Comment
Mean discharge, cubic feet per second	230	Computed from flow duration curve, personal communication, 1999
Stream slope of Twelvemile Creek	0 0015	Appendix F, 1993
Pipe unit length	40	Assumed length of each pipeline segment
Pipe material	Steel	PVC for upstream portion of dredging alternatives
Roughness height, feet	0.00015	Munson et al 1998, T 8 1, p 492, used for PVC also
Inlet loss coefficient	1	Conservative estimate based on Munson et al 1998, Figure 8 22, p 498
Outlet loss coefficient	1	Assumes outlet is into a much larger stream
Connection loss coefficient	0 08	Huang, 1994
Number of valves	4	Conservative estimate
Valve loss coefficient	0 15	Fully open gate valve, Munson et al 1998, Table 8 2, p 505
Number of elbows	10	Estimate
Elbow loss coefficient	0 4	Regular, 45 degrees, threaded, Munson et al 1998, Table 8 2, p 505
Water temperature	60	Assumed
Kinematic viscosity	1 21E-05	Munson et al 1998, Table 1 5, inside front cover
Sediment specific gravity	2 65	Assumed
d50, mm	0 7	Location BS-3, near Liberty gage, Parker and White, 1999
Pipe + installation, $/ft (steel), 6" dia	$15 90 + $17 75	From Mike Parker, email communication
Steel Pipe, 8" dia	$23 50 + $20 00	From Mike Parker, email communication
Steel Pipe, 10" dia	$36 00 + $24 00	From Mike Parker, email communication
Steel Pipe, 12" dia	$47 50 + $27 50	From Mike Parker, email communication
Steel Pipe, 14" dia	$56 00 + $37 00	From Mike Parker, email communication
Steel Pipe,16" dia	$79 50 + $44 00	From Mike Parker, email communication
Steel Pipe, 18" dia	$142 00 + $53 00	From Mike Parker, email communication
Steel Pipe, 20" dia	$108 00 + $62 00	From Mike Parker, email communication
Steel Pipe, 24" dia	$128 00 + $74 50	From Mike Parker, email communication
Ductile iron, 30" dia	$55 00 + $20 00	From Mike Parker, email communication
Ductile iron, 36" dia	$43 50 + $30 00	From Mike Parker, email communication
Lost hydropower revenue, $/cfs/hr	$0 058	From Beth Harris, CHI Energy
Net head at Woodside II Dam	38 ft	From Beth Harris, CHI Energy
Net head at Woodside I Dam	37 ft	From Beth Harris, CHI Energy

RESULTS AND DISCUSSION

Pipeline Size and Sediment Movement

The alternative designs for WSI and WSII are summarized in Table 3 and detailed results are included in the Appendix The required pipeline diameters shown are the smallest that pass at least 200 tons of sediment per day The pipeline discharge is that flow that would bypass the dams and hydropower facilities; the percent of the mean annual flow was used to estimate revenue losses The sediment concentrations in Table 2 assume that the only sediment in stream reaches downstream from the dams is from the pipeline discharge. Concentrations are very similar to the background concentration of 120 ppm and should therefore not increase turbidity or cause deposition in the immediate downstream reaches

These alternatives are capable of moving the annual incoming load past each dam during an average year "Average" is based on the long-term gaging record at the upstream Liberty gage Flows in any given year, and especially within a year, will vary significantly from the mean flow of 230 cubic feet per second During periods of high flow, more sediment will approach the HSRS inlets than be passed through the pipeline, meaning that the HSRS are not 100% efficient. No attempts have been made to characterize HSRS efficiency in this reconnaissance-level analysis.

HSRS dredging systems are shorter than HSRS bypassing systems because the sediment is collected near the dam instead of near the entrance to the reservoir As a result, the dredging pipeline diameters are smaller than the bypassing pipeline diameters It should be noted that because of the short upstream dredging pipeline length (50 ft), pipe cost was based on steel even though PVC was specified. The PVC will have to be modified, raising its likely cost to be comparable to steel The PVC was also assumed to have the same roughness as steel.

Costs

Lost hydro revenue. Revenue lost from hydropower development is cumulative for the Woodside I and II projects Annual losses vary from a low of $3,500 for short dredging systems at both dams to a high value of $11,200 for the longer bypassing systems.

Pipeline material and installation. Price estimates available for this report were for steel pipe up to 24 inches in diameter, cast iron pipe for sizes 24 inches and larger, and HDPE pipe 36 inches in diameter. Cast iron pipe is much cheaper than steel, but none of the alternatives analyzed required the larger cast iron pipe Costs reflect, therefore, the relatively high price of steel pipe Costs vary from about $160,000 for short dredging systems to about $865,000 for the longer bypassing systems

Table 3. Pipe Size Required (ft) to Pass at least 200 Tons/Day of Sediment and associated discharge and sediment concentration

Alternative	Diameter, inches	Pipeline Discharge, cfs	Percent of Mean Annual Flow	Sediment Concentration in TMC, ppm	Lost Hydro Revenue, $1000/yr	Pipeline Cost $1,000	Pipeline Installation Cost, $1,000	Total Cost, $1,000
Woodside I Dam bypass (WSIB)	16	9 5	4 1	220	4 8	143 1	79 2	227 1
Woodside I Dam dredge (WSID)	8	2 4	1	130	1.2	20	17	38.2
Woodside II Dam bypass to Lay bridge (WSIIBB)	16	8 2	3 6	130	4 2	206 7	114 4	325 3
Woodside II Dam bypass past Lay bridge downstream (WSIIBF)	20	13	5 5	140	6 4	399 6	229 4	635 4
Woodside II Dam dredge and pass to Lay bridge downstream (WSIIDB)	12	5 0	2 2	137	2.5	78 4	45 4	126 3
Woodside II Dam dredge and pass past Lay bridge (WSIIDF)	16	8 2	3 6	130	4 2	218 7	121	343 9

Shaded alternatives are the least expensive

LAYOUT OF HSRS SYSTEMS

HSRS may be deployed as either a bypass system or dredging system Conceptual layouts for each type of system will be discussed and illustrated

HSRS Bypassing

A bypassing system requires sediment to be intercepted in the portion of the free-flowing river upstream from the impoundment Once intercepted, the sediment is transported via pipeline past the dam to the discharge point

<u>Interception efficiency</u> Only bedload will be intercepted; suspended load will pass into the reservoir The limited measurements taken to date in TMC show that the suspended load made up about 20% of the total load Maximum collection efficiency is therefore limited to 80% of the total load The percentage of bedload intercepted depends upon the performance of the collection system. For this preliminary level study, it is assumed that 75% of the incoming bedload is intercepted The HSRS pipelines are designed to carry at least 170 tons of bedload material per day, using the assumed efficiency of 75%, about 130 tons per day will be intercepted and the remaining 40 tons will pass into the reservoir. If the HSRS alternative is evaluated in detail, procedures in Atkinson (1994) will be followed to refine the assumed interception efficiency

<u>Collection system</u>. The sediment collection system will consist of a 0 5-ft wide, 0 5-ft deep concrete trench installed across the streambed at a 45-degree angle in the downstream direction of flow (See Figures 1 and 2) Sliding and saltating bedload will deposit in the trench, and due to the trench angle with respect to the flow, the sediment will be moved by a trail of vortices towards the pipe entrance Once within a foot or so of the pipe entrance, local suction will be strong enough to draw sediment and water into the pipeline The trench will require the construction of an upstream and downstream apron extending at least five feet in the up- and downstream directions The aprons should begin and end with cutoff walls extending at least three feet into the streambed to protect against local erosion The first ten feet of HSRS pipeline should be contained within a concrete vault with a metal plate covering with locked access. A pump tap should be located in this vault section to allow a pump to be connected for backflushing and maintenance purposes A simple sliding gate valve should be located downstream from the tap to localize the backflushing zone.

<u>Pipeline layout</u> The HSRS pipeline should be installed above the right or left bank of TMC, whichever is more convenient for construction access. The adverse slope from the pipeline entrance to the downstream grade should be less than ten percent to minimize pipeline clogging. Pipeline segments should be supported either by shallow burial or upon concrete anchor blocks. Taps for attaching a pump for maintenance should be installed every 100 feet along the pipeline The pipeline should enter the reservoir near the dam and proceed downward to the upstream base towards the sluice gate outlet

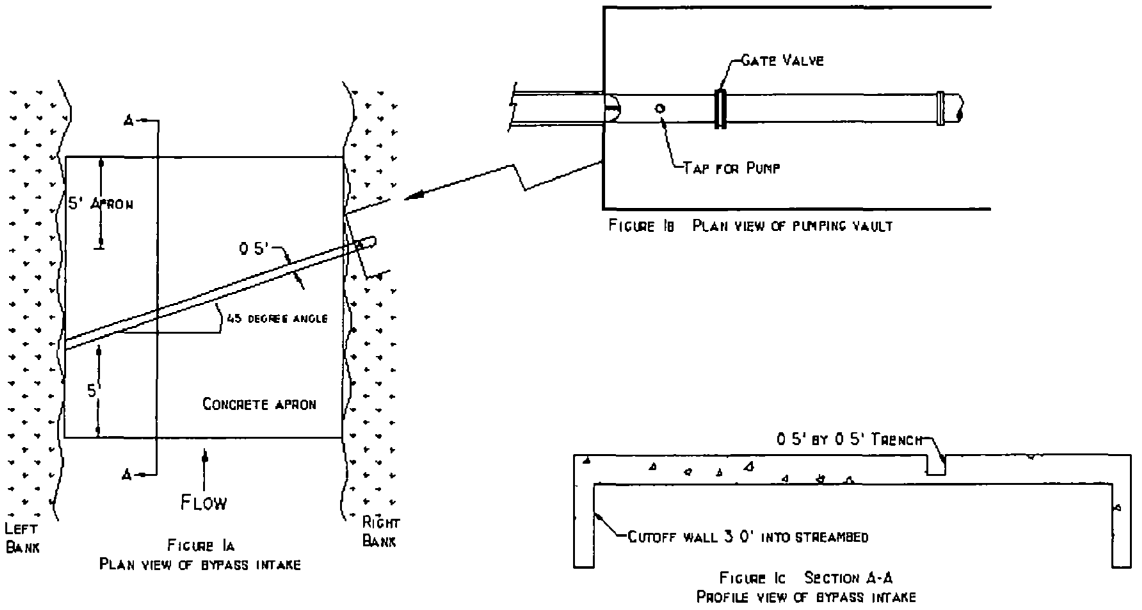

Figure 1. Layout of HSRS bypassing inlet

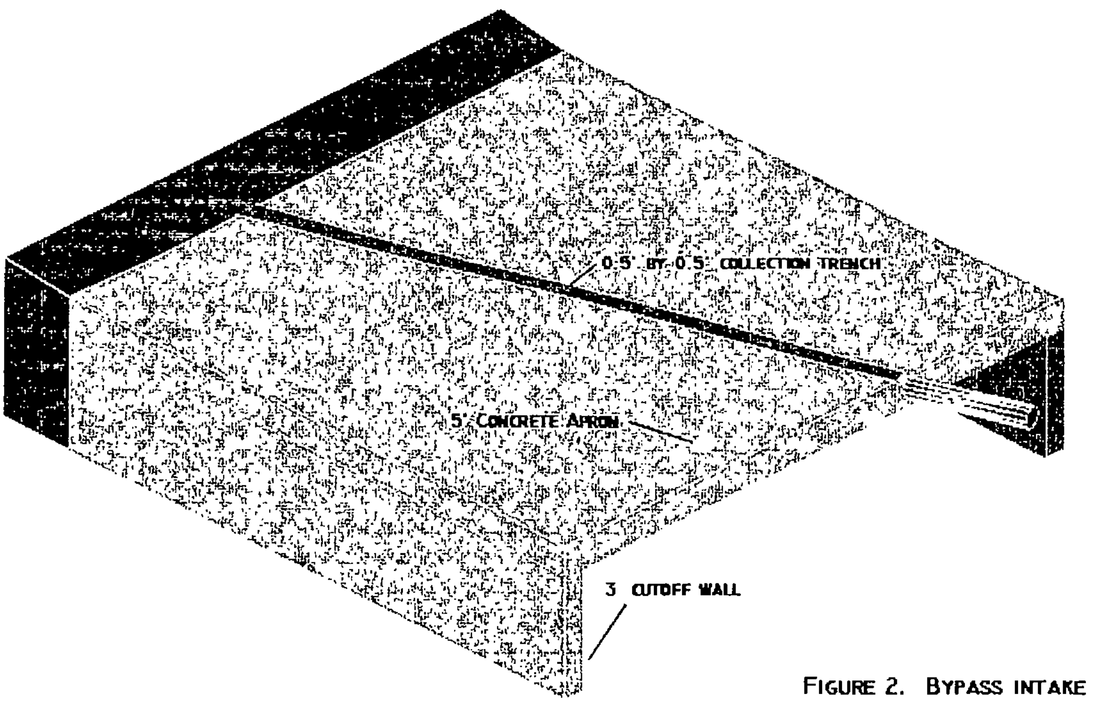

Figure 2. Perspective view of bypassing intake TMC flow is from bottom left to top right

Passage through the dam. The pipeline will pass through a special pipeline cradle constructed and installed at the base of one of the low-level outlets A simple gate valve, operable from the top of the dam, should be located on both the upstream and downstream sides of the dam to allow flexibility during maintenance The top of the pipe cradle may be fitted with a rubber gasket to provide a positive seal with the sliding gate from above.

Pipeline outlet The pipeline will proceed downstream near the left bank (looking downstream) to the outlet The outlet should be submerged under all flow conditions to prevent air from entering the pipeline system and anchored in place to avoid floatation problems

HSRS Dredging

An HSRS dredging installation will only remove sediments within 50 feet of the dam The automated system will sweep back and forth across the forebay in a circular arc whose center is the low level outlet at the dam The vacuuming action of the pipeline inlets will maintain a sediment-free zone in the vicinity of the outlets. The dredging system will remove all sediment in the forebay, including both suspended sediments and bedload sediments that have deposited from upstream. The sediments will be delivered to the forebay dredging zone either by settling from the water column (suspended load) or by cascading down the bedload depositional delta upstream from the dam

Pipeline layout The PVC pipeline will be approximately 50 feet long and will be attached to a flexible plastic pipe that is connected to the pipe leading through the low-level outlet (Figure 3) The PVC pipe will contain 16 slots, each measuring one inch high and four inches long, located on each side of the pipeline at an angle of 45 degrees beneath the pipeline horizontal centerline in an alternating fashion as shown in Figure 4 These slots represent the inlet ports through which deposited sediment will be collected and transported The far end of the pipeline will be plugged and fitted with a collar to allow towing cables to be attached. A similar collar will be located about halfway along the pipeline (Figure 4) The purpose of the cable system is to pull the pipeline in a circular arc back and forth across the bottom of the reservoir forebay The slots will collect deposited sediment along the route

MAINTENANCE ISSUES

Clogged pipe entrances and pipelines represent the major maintenance issues for HSRS installations The pipeline as it passes through the dam in either the bypassing or dredging alternative can be easily backflushed using a pump located on the dam attached to a flexible hose connected to the pipeline at a tap location. The dredging alternative collection pipeline may also be easily backflushed using a similar pump system mounted on the dam

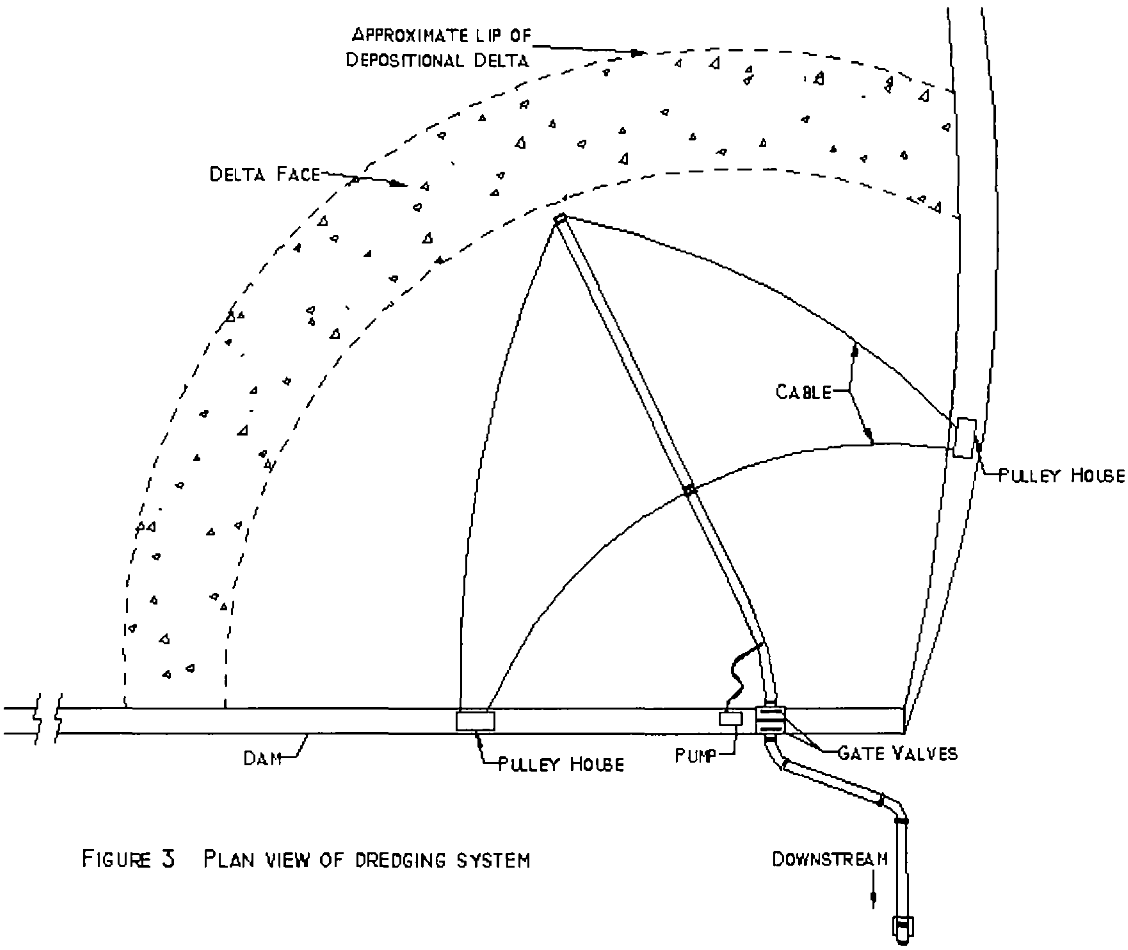

FIGURE 3 PLAN VIEW OF DREDGING SYSTEM

The bypassing system may become clogged at the entrance or along its length. A pump tap is included near the entrance to backflush the first several feet where clogging may be more common As recommended in the layout section of the report, taps will be located along the bypass often enough to allow local backflushing Access to the pipeline may be difficult - a path along the pipeline should be maintained for access purposes

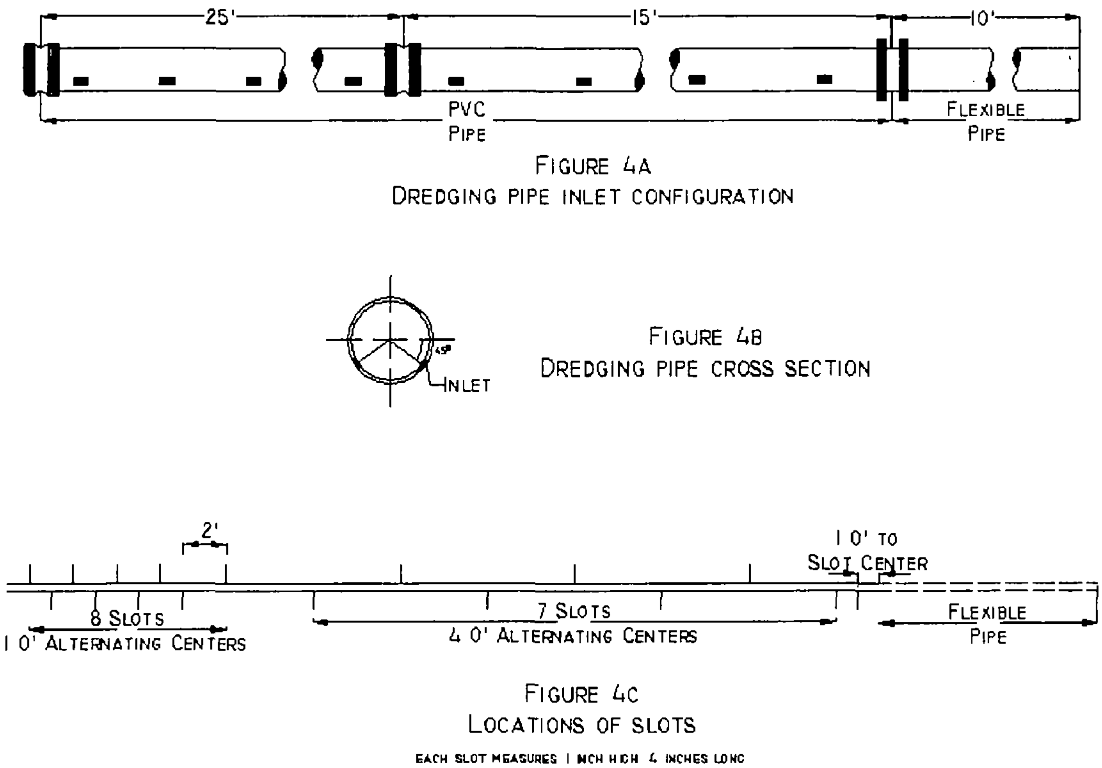

Figure 4. Details of dredging inlets of intake pipe

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

HSRS is a feasible method for maintaining a sediment balance across both Woodside I and II dams. Sediment concentrations in the pipeline will closely match those in the existing TMC, thus avoiding increases in turbidity over background levels upstream from the projects. The relatively low concentrations also will remain in transport downstream and not alter the present riffle-pool nature of the reach below Woodside II dam HSRS only 1 - 4% of the mean annual discharge to move 200 tons/day past the dams, representing a commensurate loss of hydropower revenue. The simple nature of the pipeline systems makes maintenance relatively simple and inexpensive. The continuous operation of the HSRS will not interfere with hydropower production and will not introduce pulses of sediment downstream that would result from periodic sluicing The bypassing alternative requires no power source and will likely intercept about 75% of the sediment load in TMC, dramatically decreasing the need for maintenance dredging or flushing near the dam The dredging systems are very inexpensive and would maintain a 50-foot radius sediment-free zone in front of the power intakes.

Recommendations

It is recommend that HSRS dredging systems for Woodside I and II dams be investigated more thoroughly to determine economic feasibility. The low-level outlets at each dam are scheduled for replacement; passing a pipeline through the lower portion of the new outlets would accommodate HSRS dredging systems. The only remaining step is to work out details for automatically and remotely operating the system to sweep the forebay at a regular interval

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Personal communication with Theodore W Cooney, email received 23 November 1999

APPENDIX

Calculations and Spreadsheet Results

Alternative (Filename WSIB)
Woodside I dam with bypassing system from farther upstream

Input Data	Values
Units (feet or meters)	ft
U S WSEL	137
D S WSEL or outlet	100
Mean discharge	230
stream slope	0 0015
Pipeline length	1800
Downstream length	800
Pipe unit length	40
Pipe material	Steel
Roughness height	0 00015
Inlet loss coefficient	1
Outlet loss coefficient	1
Connection loss coefficient	0 08
Number of valves	4
Valve loss coefficient:	0 15
Number of elbows	10
Elbow loss coefficient	0 4
Water temperature	60
Kinematic viscosity	1 21E-05
Sediment specific gravity	2 65
d50, mm·	0 7

Solution Parameters	Values
Number of pipeline segments	45
Total head available.	38 2
Sum of minor losses	10 2
Composite drag coefficient, Cd	2
Gravity	32 2
Pipeline transport coefficient, K	211
Pipeline transport exponent, m	-1 31
Exponent 1 in Eq (12)	-0 552
Exponent 2 in Eq (12)	0 448
Exponent 3 in Eq (12)	1 810
Exponent in Eq (11)	-0 276

Pipeline Costs	Dia , in	Pipe	Install
Pipe & installation, $/ft (steel)	6	$15 90	$17 75
Steel Pipe	8	$23 50	$20 00
Steel Pipe	10	$36 00	$24 00
Steel Pipe	12	$47 50	$27 50
Steel Pipe	14	$56 00	$37 00
Steel Pipe	16	$79 50	$44.00
Steel Pipe	18	$142 00	$53 00
Steel Pipe	20	$108 00	$62 00
Steel Pipe	24	$128 00	$74.50
Ductile iron	30	$55 00	$20 00
Ductile iron	36	$43 50	$30 00

Hydroelectricity Revenue lost	
Dollars lost per cfs per hour	$0 058

Computed parameters	6 in 0 5	Values for Indicated Pipe Diameter 8 in 0 667	12 in 1	16 in 1 33	18 in 1 5	20 in 1 667	24 in 2	30 in 2 5
Alpha	9839	14352	24395	35444	41494	47647	60486	81022
Bracket in Eq (12)	2 464E-05	3 006E-05	3 975E-05	4 839E-05	5 258E-05	5 655E-05	6 412E-05	7 480E-05
Assumed pipeline velocity	3 9	4.7	5 9	6 8	7 3	7 6	8 25	9 1
Assumed Darcy-Weisbach f	0 0182	0 0168	0 0151	0 014	0 0136	0 0133	0 0128	0 0122
First calculated value of Jm	0 020	0 019	0 018	0 017	0 017	0 016	0 015	0 014
First calc Qs (L^3/T)	0 004	0 008	0 024	0 051	0 068	0 089	0 135	0 219
First calculated value of Vm	3 97	4 70	5 89	6 85	7 25	7 64	8 28	9 07
Corresponding Reynolds Number	163957	258900	486543	753270	898682	1051932	1368982	1874365
Calculated value of fm	0 0182	0 0168	0 0151	0 0140	0 0136	0 0133	0 0128	0 0122
2nd calc Value of Jm	0 020	0 019	0 018	0 017	0 017	0 016	0 015	0 014
2nd value of Qs (L^3/T)	0 004	0 008	0.025	0 051	0 069	0 088	0 135	0 222
2nd value of Vm	3 96	4 70	5 90	6 84	7.26	7 63	8 28	9 10
2nd Reynolds Number	163722	259158	487469	751344	899552	1050629	1369155	1880976
2nd value of fm close to above?	0 0182	0 0168	0 0151	0 0140	0 0136	0 0133	0 0128	0 0122
WSIB		Values for Indicated Pipe Diameter						
Summary	6 in	8 in	12 in	16 in	18 in	20 in	24 in	30 in
Final value of Qs in BG Tons/Day	26	58	175	364	490	631	966	1586
Pipeline discharge	0 8	1 6	4 6	9 5	12 8	16 6	26 0	44.7
Percent of mean discharge	0 3	0 7	2 0	4 1	5 6	7 2	11 3	19 4
Pipeline concentration, %	0 46	0 50	0 53	0 54	0 54	0 53	0 52	0 50
Pipeline concentration, ppm	4625	4964	5291	5359	5353	5310	5195	4967
Stream concentration, %	0 00	0 00	0 01	0 02	0 03	0 04	0 06	0 10
Stream concentration, ppm	16	35	107	221	298	384	588	965
Lost hydro revenue, $/year	$395	$835	$2,354	$4,825	$6,515	$8,457	$13,222	$22,705
Pipeline material cost	$28,620	$42,300	$85,500	$143,100	$255,600	$194,400	$230,400	$99,000
Pipeline installation cost	$31,950	$36,000	$49,500	$79,200	$95,400	$111,600	$134,100	$36,000
Total pipeline cost	$60,570	$78,300	$135,000	$222,300	$351,000	$306,000	$364,500	$135,000

Alternative (Filename WSID)
Woodside I dam with dredging just upstream from the dam
to a point downstream

Input Data	Values
Units (feet or meters)	ft
U S WSEL	137
D S WSEL or outlet	100
Mean discharge	230
stream slope	0 0015
Pipeline length	950
Downstream length	800
Pipe unit length	40
Pipe material·	Steel
Roughness height	0 00015
Inlet loss coefficient.	1
Outlet loss coefficient	1
Connection loss coefficient	0 08
Number of valves	4
Valve loss coefficient	0 15
Number of elbows	10
Elbow loss coefficient	0.4
Water temperature	60
Kinematic viscosity	1 21E-05
Sediment specific gravity	2 65
d50, mm	0 7

Solution Parameters	Values
Number of pipeline segments	24
Total head available	38 2
Sum of minor losses	8 5
Composite drag coefficient, Cd	2
Gravity	32 2
Pipeline transport coefficient, K	211
Pipeline transport exponent, m	-1 31
Exponent 1 in Eq (12)	-0 552
Exponent 2 in Eq (12)	0 448
Exponent 3 in Eq (12)	1 810
Exponent in Eq (11)	-0 276

Pipeline Costs	Dia , in	Pipe	Install
Pipe & installation, $/ft (steel)	6	$15 90	$17 75
Steel Pipe	8	$23 50	$20 00
Steel Pipe	10	$36 00	$24 00
Steel Pipe	12	$47 50	$27 50
Steel Pipe	14	$56 00	$37 00
Steel Pipe	16	$79 50	$44 00
Steel Pipe	18	$142 00	$53 00
Steel Pipe	20	$108 00	$62 00
Steel Pipe	24	$128 00	$74 50
Ductile iron	30	$55 00	$20 00
Ductile iron	36	$43 50	$30.00

Hydroelectricity Revenue lost	
Dollars lost per cfs per hour	$0 058

	Values for Indicated Pipe Diameter							
	6 in	8 in	12 in	16 in	18 in	20 in	24 in	30 in
Computed parameters	0 5	0 667	1	1 33	1 5	1 667	2	2.5
Alpha	9839	14352	24395	35444	41494	47647	60486	81022
Bracket in Eq (12)	2 464E-05	3 006E-05	3 975E-05	4 839E-05	5 258E-05	5 655E-05	6 412E-05	7 480E-05
Assumed pipeline velocity	5 4	6 4	7.9	9	9 45	9 9	10 6	11 48
Assumed Darcy-Weisbach f	0 0176	0 0162	0 0147	0 0137	0 0134	0 013	0 0125	0 012
First calculated value of Jm	0 036	0.035	0 032	0 029	0 028	0 027	0 025	0 022
First calc Qs (L^3/T)	0 011	0 025	0 069	0 138	0 180	0 228	0.336	0 512
First calculated value of Vm	5 44	6 40	7 86	9 00	9 47	9 91	10 65	11 47
Corresponding Reynolds Number	224838	352798	649876	989358	1174070	1365780	1760424	2369220
Calculated value of fm	0 0176	0 0162	0 0147	0 0137	0 0133	0 0130	0 0125	0 0120
2nd calc Value of Jm	0 036	0 035	0 032	0 029	0 028	0 027	0 024	0 022
2nd value of Qs (L^3/T)	0 011	0.025	0 070	0 138	0 181	0 227	0 331	0 517
2nd value of Vm	5 44	6 39	7 89	9 00	9.49	9 90	10 61	11 50
2nd Reynolds Number	224935	352461	651691	989361	1175938	1363763	1753938	2376373
2nd value of fm close to above?	0 0176	0 0162	0 0147	0 0137	0 0133	0 0130	0 0125	0 0119

WSID	Values for Indicated Pipe Diameter							
Summary	6 in	8 in	12 in	16 in	18 in	20 in	24 in	30 in
Final value of Qs in BG Tons/Day	81	177	501	984	1293	1623	2367	3696
Pipeline discharge	1 1	2 2	6 2	12 5	16 8	21 6	33 3	56 5
Percent of mean discharge	0 5	1 0	2 7	5 4	7 3	9 4	14 5	24 5
Pipeline concentration, %	1 06	1 11	1 13	1 10	1 08	1 05	0 99	0 92
Pipeline concentration, ppm	10630	11110	11321	11021	10801	10518	9940	9164
Stream concentration, %	0 00	0 01	0 03	0 06	0 08	0 10	0 14	0 22
Stream concentration, ppm	49	108	305	599	787	988	1441	2250
Lost hydro revenue, $/year	$543	$1,135	$3,147	$6,354	$8,517	$10,977	$16,938	$28,685
Pipeline material cost	$15,105	$22,325	$45,125	$75,525	$134,900	$102,600	$121,600	$52,250
Pipeline installation cost	$16,863	$19,000	$26,125	$41,800	$50,350	$58,900	$70,775	$19,000
Total pipeline cost	$31,968	$41,325	$71,250	$117,325	$185,250	$161,500	$192,375	$71,250

Alternative (Filename WSIIBB)
Woodside II dam bypass sediment past dam to bridge

Input Data	Values
Units (feet or meters)	ft
U S WSEL	138
D S WSEL or outlet	100
Mean discharge	230
stream slope	0 0015
Pipeline length	2600
Downstream length	1600
Pipe unit length.	40
Pipe material	Steel
Roughness height	0 00015
Inlet loss coefficient	1
Outlet loss coefficient.	1
Connection loss coefficient.	0 08
Number of valves.	4
Valve loss coefficient	0 15
Number of elbows·	10
Elbow loss coefficient·	0 4
Water temperature	60
Kinematic viscosity·	1 21E-05
Sediment specific gravity	2 65
d50, mm	0 7

Solution Parameters	Values
Number of pipeline segments	65
Total head available	40 4
Sum of minor losses	11 8
Composite drag coefficient, Cd	2
Gravity	32 2
Pipeline transport coefficient, K	211
Pipeline transport exponent, m	-1 31
Exponent 1 in Eq (12)	-0 552
Exponent 2 in Eq (12)	0 448
Exponent 3 in Eq (12)	1 810
Exponent in Eq (11)	-0 276

Pipeline Costs	Dia , in	Pipe	Install
Pipe & installation, \$/ft (steel)	6	\$15 90	\$17 75
Steel Pipe	8	\$23 50	\$20 00
Steel Pipe	10	\$36 00	\$24 00
Steel Pipe	12	\$47 50	\$27 50
Steel Pipe	14	\$56 00	\$37 00
Steel Pipe	16	\$79 50	\$44 00
Steel Pipe	18	\$142 00	\$53 00
Steel Pipe	20	\$108 00	\$62 00
Steel Pipe	24	\$128 00	\$74 50
Ductile iron	30	\$55 00	\$20 00
Ductile iron	36	\$43 50	\$30 00

Hydroelectricity Revenue lost	
Dollars lost per cfs per hour	\$0 058

	Values for Indicated Pipe Diameter							
	6 in	8 in	12 in	16 in	18 in	20 in	24 in	30 in
Computed parameters	0 5	0 667	1	1 33	1 5	1 667	2	2 5
Alpha.	9839	14352	24395	35444	41494	47647	60486	81022
Bracket in Eq (12)	2 464E-05	3 006E-05	3 975E-05	4 839E-05	5 258E-05	5 655E-05	6 412E-05	7 480E-05
Assumed pipeline velocity	3 4	4 05	5 1	5 9	6 3	6 6	7 3	8 1
Assumed Darcy-Weisbach f	0 0186	0 0171	0 0153	0 0142	0 0138	0 0135	0 0129	0 0123
First calculated value of Jm	0 015	0 014	0 014	0 013	0 013	0 012	0 012	0 011
First calc Qs (L^3/T)	0 002	0 005	0 014	0 031	0 042	0 054	0 084	0 139
First calculated value of Vm	3 38	4 02	5 08	5 94	6 32	6 66	7 26	8 00
Corresponding Reynolds Number	139563	221651	419915	653260	783189	917714	1199328	1652056
Calculated value of fm	0 0186	0 0171	0 0153	0 0142	0 0138	0 0135	0 0129	0 0123
2nd calc Value of Jm	0 015	0 014	0 014	0 013	0 013	0 012	0 012	0 011
2nd value of Qs (L^3/T)	0 002	0 005	0 014	0 030	0 041	0 054	0 084	0 142
2nd value of Vm	3 38	4 03	5 09	5 93	6 31	6 66	7 27	8 05
2nd Reynolds Number	139649	221927	420345	652147	782739	917136	1201636	1662610
2nd value of fm close to above?	0 0186	0 0171	0 0153	0 0142	0 0138	0 0135	0 0129	0 0123
WSIIBB		Values for Indicated Pipe Diameter						
Summary	6 in	8 in	12 in	16 in	18 in	20 in	24 in	30 in
Final value of Qs in BG Tons/Day	14	33	102	218	296	386	602	1014
Pipeline discharge	0 7	1 4	4 0	8 2	11 2	14 5	22 8	39 5
Percent of mean discharge	0 3	0.6	1 7	3 6	4 9	6 3	9 9	17 2
Pipeline concentration, %	0 30	0 33	0 36	0 37	0 37	0 37	0 37	0 36
Pipeline concentration, ppm	3049	3306	3589	3698	3718	3719	3690	3595
Stream concentration, %	0 00	0 00	0 01	0 01	0 02	0 02	0 04	0.06
Stream concentration, ppm	9	20	62	133	180	235	366	617
Lost hydro revenue, $/year	$337	$715	$2,030	$4,188	$5,669	$7,382	$11,604	$20,070
Pipeline material cost	$41,340	$61,100	$123,500	$206,700	$369,200	$280,800	$332,800	$143,000
Pipeline installation cost	$46,150	$52,000	$71,500	$114,400	$137,800	$161,200	$193,700	$52,000
Total pipeline cost	$87,490	$113,100	$195,000	$321,100	$507,000	$442,000	$526,500	$195,000

Alternative (Filename WSIIBF)
Woodside II dam bypass sediment past dam past bridge

Input Data	Values
Units (feet or meters):	ft
U S WSEL	138
D S WSEL or outlet	100
Mean discharge	230
stream slope	0 0015
Pipeline length	3700
Downstream length	2700
Pipe unit length	40
Pipe material	Steel
Roughness height	0 00015
Inlet loss coefficient	1
Outlet loss coefficient	1
Connection loss coefficient	0 08
Number of valves	4
Valve loss coefficient	0 15
Number of elbows	10
Elbow loss coefficient	0 4
Water temperature	60
Kinematic viscosity	1 21E-05
Sediment specific gravity	2 65
d50, mm	0 7

Solution Parameters	Values
Number of pipeline segments.	93
Total head available	42 05
Sum of minor losses	14
Composite drag coefficient, Cd	2
Gravity	32 2
Pipeline transport coefficient, K	211
Pipeline transport exponent, m	-1 31
Exponent 1 in Eq (12)	-0 552
Exponent 2 in Eq (12)	0 448
Exponent 3 in Eq (12)	1 810
Exponent in Eq (11)	-0 276

Pipeline Costs	Dia , in	Pipe	Install
Pipe & installation, $/ft (steel)	6	$15 90	$17 75
Steel Pipe	8	$23 50	$20 00
Steel Pipe	10	$36 00	$24 00
Steel Pipe	12	$47 50	$27 50
Steel Pipe	14	$56 00	$37 00
Steel Pipe	16	$79 50	$44 00
Steel Pipe	18	$142 00	$53 00
Steel Pipe	20	$108 00	$62 00
Steel Pipe	24	$128 00	$74 50
Ductile iron	30	$55 00	$20 00
Ductile iron	36	$43 50	$30 00

Hydroelectricity Revenue lost	
Dollars lost per cfs per hour	$0 058

	Values for Indicated Pipe Diameter								
	6 in	8 in	12 in	16 in	18 in	20 in	24 in	30 in	36 in
Computed parameters	0 5	0 667	1	1 33	1 5	1 667	2	2 5	3
Alpha	9839	14352	24395	35444	41494	47647	60486	81022	102880
Bracket in Eq (12)	2 464E-05	3 006E-05	3 975E-05	4 839E-05	5 258E-05	5 655E-05	6 412E-05	7 480E-05	8 482E-05
Assumed pipeline velocity	2 85	3.43	4 35	5 1	5 45	5 8	6 3	7 05	7 7
Assumed Darcy-Weisbach f	0 019	0 0174	0 0155	0.0144	0 014	0 0136	0 0131	0.0124	0 0119
First calculated value of Jm	0 011	0 011	0 010	0 010	0 010	0 009	0 009	0 008	0 008
First calc Qs (L^3/T)	0 001	0 003	0 008	0 018	0 024	0 032	0 050	0 086	0 129
First calculated value of Vm	2 87	3 43	4 37	5 12	5 45	5 76	6 30	7 00	7 57
Corresponding Reynolds Number	118742	189291	360846	562446	675639	793396	1042039	1447272	1876154
Calculated value of fm	0 0190	0.0174	0 0155	0.0144	0 0140	0 0136	0 0131	0 0124	0 0119
2nd calc Value of Jm	0 011	0 011	0 010	0 010	0 010	0 009	0 009	0 008	0 008
2nd value of Qs (L^3/T)	0 001	0 003	0 008	0 018	0 024	0 032	0 051	0 086	0 132
2nd value of Vm	2 87	3 43	4 36	5 11	5 45	5 76	6 31	7 02	7 61
2nd Reynolds Number	118675	189179	360214	561648	675654	793361	1043290	1449644	1887949
2nd value of fm close to above?	0 0190	0 0174	0 0155	0 0144	0 0140	0 0136	0 0131	0 0124	0 0119

WSIIBF	Values for Indicated Pipe Diameter								
<u>Summary</u>	6 in	8 in	12 in	16 in	18 in	20 in	24 in	30 in	36 in
Final value of Qs in BG Tons/Day	8	19	59	127	174	228	361	618	942
Pipeline discharge	0 6	1 2	3 4	7.1	9.6	12 6	19 8	34 4	53 8
Percent of mean discharge	0 2	0 5	1 5	3 1	4 2	5.5	8 6	15 0	23 4
Pipeline concentration, %	0 20	0 22	0 24	0.25	0 25	0 25	0 25	0 25	0 24
Pipeline concentration, ppm	1991	2176	2395	2500	2529	2544	2548	2510	2450
Stream concentration, %	0 00	0 00	0 00	0 01	0 01	0 01	0 02	0 04	0 06
Stream concentration, ppm	5	11	36	77	106	139	220	376	573
Lost hydro revenue, $/year	$287	$609	$1,739	$3,607	$4,894	$6,386	$10,075	$17,499	$27,348
Pipeline material cost	$58,830	$86,950	$175,750	$294,150	$525,400	$399,600	$473,600	$203,500	$160,950
Pipeline installation cost	$65,675	$74,000	$101,750	$162,800	$196,100	$229,400	$275,650	$74,000	$111,000
Total pipeline cost	$124,505	$160,950	$277,500	$456,950	$721,500	$629,000	$749,250	$277,500	$271,950

Alternative. (Filename WSIIDB)
Woodside II dam dredge sediment and pass to bridge

Input Data	Values
Units (feet or meters).	ft
U S WSEL	138
D S WSEL or outlet	100
Mean discharge	230
stream slope	0 0015
Pipeline length	1650
Downstream length	1600
Pipe unit length	40
Pipe material	Steel
Roughness height	0 00015
Inlet loss coefficient	1
Outlet loss coefficient	1
Connection loss coefficient	0 08
Number of valves	4
Valve loss coefficient	0 15
Number of elbows·	10
Elbow loss coefficient	0 4
Water temperature	60
Kinematic viscosity	1 21E-05
Sediment specific gravity	2 65
d50, mm	0.7

Solution Parameters	Values
Number of pipeline segments	41
Total head available	40 4
Sum of minor losses	9 9
Composite drag coefficient, Cd	2
Gravity	32 2
Pipeline transport coefficient, K	211
Pipeline transport exponent, m	-1 31
Exponent 1 in Eq (12)	-0 552
Exponent 2 in Eq (12)	0 448
Exponent 3 in Eq (12)	1 810
Exponent in Eq (11)	-0 276

Pipeline Costs	Dia , in	Pipe	Install
Pipe & installation, $/ft (steel)	6	$15 90	$17 75
Steel Pipe	8	$23 50	$20 00
Steel Pipe	10	$36 00	$24 00
Steel Pipe	12	$47 50	$27 50
Steel Pipe	14	$56 00	$37 00
Steel Pipe	16	$79 50	$44 00
Steel Pipe	18	$142 00	$53 00
Steel Pipe	20	$108 00	$62 00
Steel Pipe	24	$128 00	$74 50
Ductile iron	30	$55 00	$20 00
Ductile iron	36	$43 50	$30 00

Hydroelectricity Revenue lost	
Dollars lost per cfs per hour	$0 058

Computed parameters	6 in 0 5	Values for Indicated Pipe Diameter 8 in 0 667	12 in 1	16 in 1 33	18 in 1 5	20 in 1 667	24 in 2	30 in 2 5	36 in 3
Alpha:	9839	14352	24395	35444	41494	47647	60486	81022	102880
Bracket in Eq (12)	2 464E-05	3 006E-05	3 975E-05	4 839E-05	5 258E-05	5 655E-05	6 412E-05	7 480E-05	8 482E-05
Assumed pipeline velocity	4 2	5	6 3	7 3	7 7	8.1	8 8	9 7	10 3
Assumed Darcy-Weisbach f.	0 018	0 016	0 0149	0 0139	0 0135	0 0132	0 0127	0 0121	0 0116
First calculated value of Jm	0 023	0 022	0 021	0 020	0 019	0 018	0 017	0 016	0 015
First calc Qs (L^3/T)	0 005	0 011	0 032	0 066	0 089	0 114	0 172	0 277	0 412
First calculated value of Vm	4 28	5 16	6 34	7.34	7 79	8 18	8 85	9 67	10 43
Corresponding Reynolds Number	176702	284401	524039	806436	965963	1126566	1463354	1998879	2586428
Calculated value of fm	0 0180	0 0166	0 0149	0 0139	0 0135	0 0132	0 0127	0 0121	0 0116
2nd calc Value of Jm	0 023	0 022	0 021	0 019	0.019	0 018	0 017	0 016	0 014
2nd value of Qs (L^3/T)	0 005	0 011	0 032	0 065	0 087	0 112	0 171	0 278	0 397
2nd value of Vm	4 27	5 05	6 32	7 32	7 75	8 15	8 83	9 69	10 32
2nd Reynolds Number	176258	278303	522646	804409	961070	1122223	1460233	2002235	2559566
2nd value of fm close to above?	0 0180	0 0166	0 0149	0 0139	0 0135	0 0132	0 0127	0 0121	0 0116
WSIIDB									

Summary	6 in	Values for Indicated Pipe Diameter 8 in	12 in	16 in	18 in	20 in	24 in	30 in	36 in
Final value of Qs in BG Tons/Day	34	75	225	465	623	802	1219	1988	2835
Pipeline discharge	0 8	1 8	5 0	10 2	13 7	17 8	27 8	47 6	73 0
Percent of mean discharge	0.4	0 8	2 2	4 4	6 0	7 7	12 1	20 7	31 7
Pipeline concentration, %	0 56	0 60	0 64	0 64	0 64	0 63	0 61	0 59	0 54
Pipeline concentration, ppm	5611	5983	6351	6408	6366	6311	6150	5850	5438
Stream concentration, %	0 00	0 00	0 01	0 03	0 04	0 05	0 07	0 12	0 17
Stream concentration, ppm	20	46	137	283	379	488	742	1210	1725
Lost hydro revenue, $/year	$426	$896	$2,524	$5,166	$6,961	$9,033	$14,101	$24,169	$37,076
Pipeline material cost	$26,235	$38,775	$78,375	$131,175	$234,300	$178,200	$211,200	$90,750	$71,775
Pipeline installation cost	$29,288	$33,000	$45,375	$72,600	$87,450	$102,300	$122,925	$33,000	$49,500
Total pipeline cost	$55,523	$71,775	$123,750	$203,775	$321,750	$280,500	$334,125	$123,750	$121,275

Alternative. (Filename WSIIDF)
Woodside II dam dredge sediment to a point past the bridge

Input Data	Values
Units (feet or meters)	ft
U S WSEL	138
D S WSEL or outlet	100
Mean discharge	230
stream slope	0 0015
Pipeline length	2750
Downstream length	2700
Pipe unit length	40
Pipe material	Steel
Roughness height	0 00015
Inlet loss coefficient	1
Outlet loss coefficient	1
Connection loss coefficient	0 08
Number of valves	4
Valve loss coefficient	0 15
Number of elbows	10
Elbow loss coefficient	0 4
Water temperature·	60
Kinematic viscosity.	1 21E-05
Sediment specific gravity	2 65
d50, mm.	0 7

Solution Parameters	Values
Number of pipeline segments	69
Total head available	42 05
Sum of minor losses·	12 1
Composite drag coefficient, Cd	2
Gravity	32 2
Pipeline transport coefficient, K	211
Pipeline transport exponent, m	-1 31
Exponent 1 in Eq (12)	-0 552
Exponent 2 in Eq (12)	0 448
Exponent 3 in Eq (12)	1 810
Exponent in Eq (11)	-0 276

Pipeline Costs	Dia , in	Pipe	Install
Pipe & installation, $/ft (steel)	6	$15 90	$17 75
Steel Pipe	8	$23 50	$20 00
Steel Pipe	10	$36 00	$24 00
Steel Pipe	12	$47 50	$27 50
Steel Pipe	14	$56 00	$37 00
Steel Pipe	16	$79 50	$44 00
Steel Pipe	18	$142 00	$53 00
Steel Pipe	20	$108 00	$62 00
Steel Pipe	24	$128 00	$74 50
Ductile iron	30	$55 00	$20 00
Ductile iron	36	$43 50	$30 00

Hydroelectricity Revenue lost	
Dollars lost per cfs per hour	$0 058

	Values for Indicated Pipe Diameter								
	6 in	8 in	12 in	16 in	18 in	20 in	24 in	30 in	36 in
Computed parameters	0 5	0 667	1	1 33	1 5	1 667	2	2 5	3
Alpha	9839	14352	24395	35444	41494	47647	60486	81022	102880
Bracket in Eq (12)	2 464E-05	3 006E-05	3 975E-05	4 839E-05	5 258E-05	5 655E-05	6 412E-05	7 480E-05	8 482E-05
Assumed pipeline velocity	3 3	4	5	5 9	6 25	6 6	7 2	8	8 6
Assumed Darcy-Weisbach f	0 0186	0 0171	0 0153	0 0142	0 0138	0 0135	0 0129	0 0123	0 0118
First calculated value of Jm	0 015	0 014	0 014	0 013	0 013	0 012	0 012	0 011	0 010
First calc Qs (L^3/T)	0 002	0 005	0 014	0 030	0 041	0.053	0 083	0 139	0 210
First calculated value of Vm	3 36	4 00	5 06	5 90	6 29	6 62	7 25	8 00	8 66
Corresponding Reynolds Number	138722	220222	418033	648934	779512	912032	1197601	1652321	2147354
Calculated value of fm	0 0186	0.0171	0 0153	0 0142	0 0138	0 0135	0 0129	0 0123	0 0118
2nd calc Value of Jm	0 015	0 014	0 014	0 013	0 013	0 012	0 012	0 011	0 010
2nd value of Qs (L^3/T)	0 002	0 005	0.014	0 030	0 041	0 053	0 083	0 139	0 207
2nd value of Vm	3 35	4 00	5.05	5 90	6 28	6 62	7 23	8 01	8 63
2nd Reynolds Number	138577	220305	417536	648435	778366	912628	1195246	1654199	2139800
2nd value of fm close to above?	0 0186	0 0171	0 0153	0 0142	0 0138	0.0135	0 0129	0 0123	0 0118
WSIIDF		Values for Indicated Pipe Diameter							
Summary	6 in	8 in	12 in	16 in	18 in	20 in	24 in	30 in	36 in
Final value of Qs in BG Tons/Day	14	32	100	213	290	379	591	996	1482
Pipeline discharge	0 7	1.4	4 0	8 2	11 1	14 5	22 7	39 3	61 0
Percent of mean discharge	0 3	0 6	1 7	3 6	4 8	6 3	9 9	17 1	26 5
Pipeline concentration, %	0 30	0 32	0.35	0 36	0 37	0 37	0 36	0 35	0 34
Pipeline concentration, ppm	2988	3244	3526	3643	3664	3672	3639	3547	3401
Stream concentration, %	0 00	0 00	0 01	0 01	0 02	0 02	0 04	0 06	0 09
Stream concentration, ppm	9	20	61	130	177	231	359	606	902
Lost hydro revenue, $/year	$335	$710	$2,016	$4,164	$5,637	$7,346	$11,542	$19,968	$30,996
Pipeline material cost	$43,725	$64,625	$130,625	$218,625	$390,500	$297,000	$352,000	$151,250	$119,625
Pipeline installation cost	$48,813	$55,000	$75,625	$121,000	$145,750	$170,500	$204,875	$55,000	$82,500
Total pipeline cost	$92,538	$119,625	$206,250	$339,625	$536,250	$467,500	$556,875	$206,250	$202,125

APPENDIX C

Comparison of 1992 and 1999 Crossection Surveys

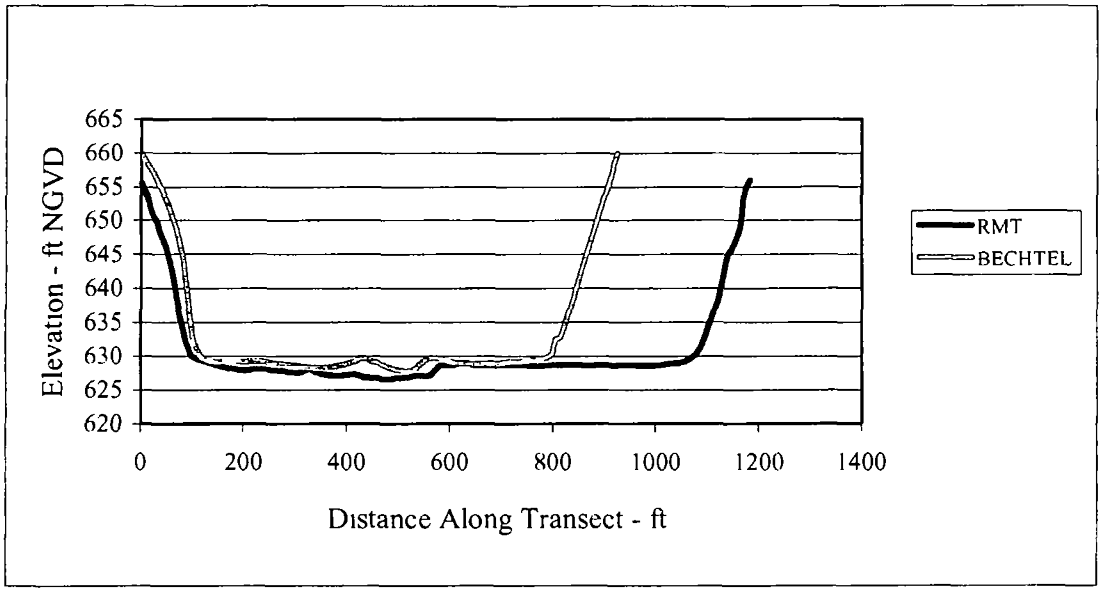


Figure A1 Transect H comparison

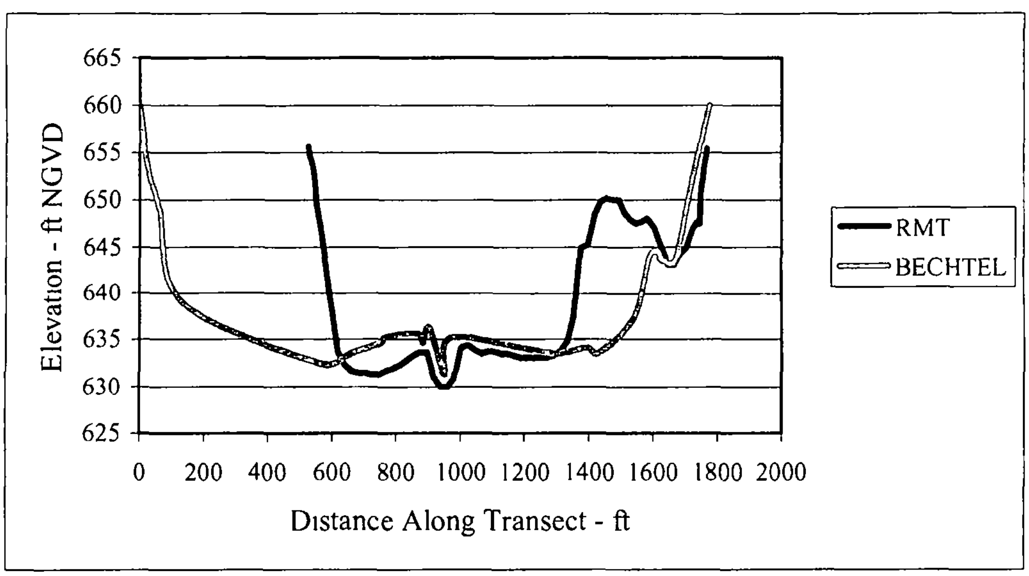


Figure A2 Transect I comparison

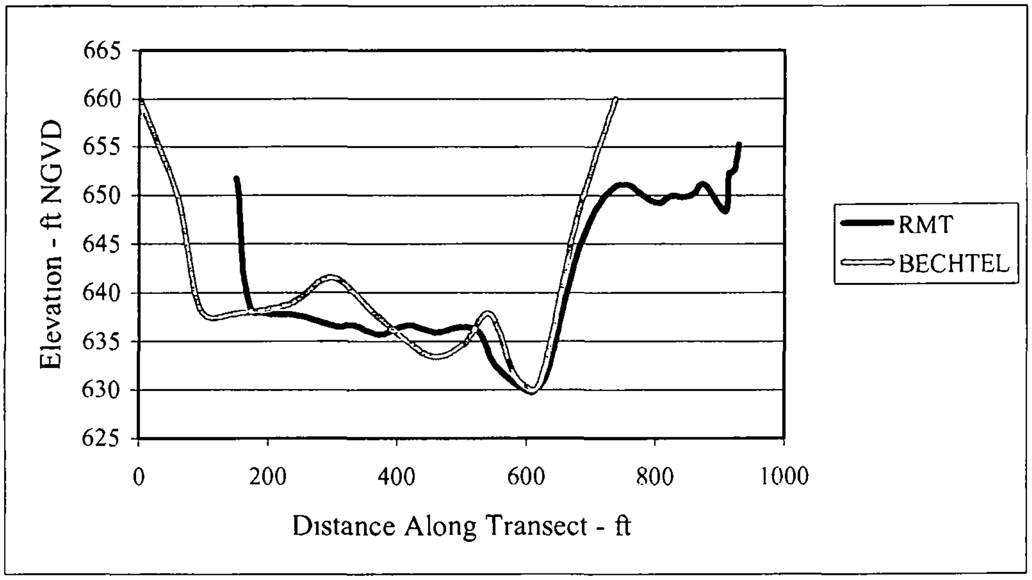


Figure A3 Transect J comparison

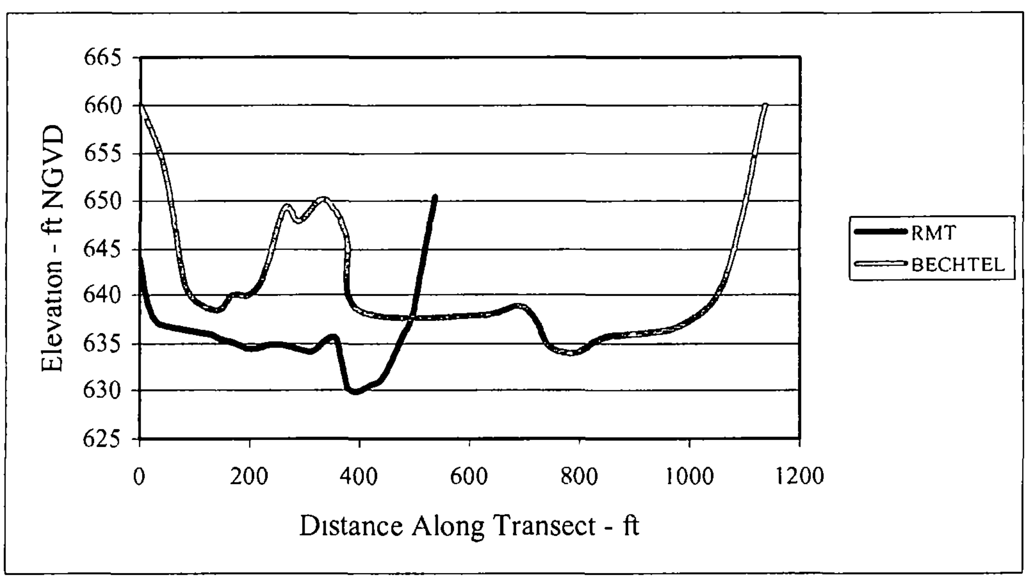


Figure A4 Transect K comparison

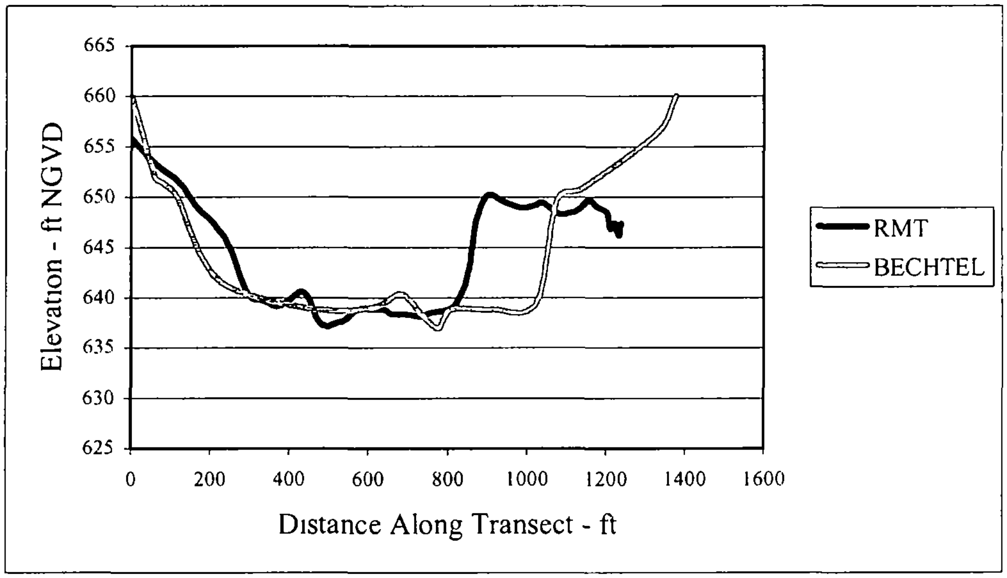


Figure A5 Transect L comparison

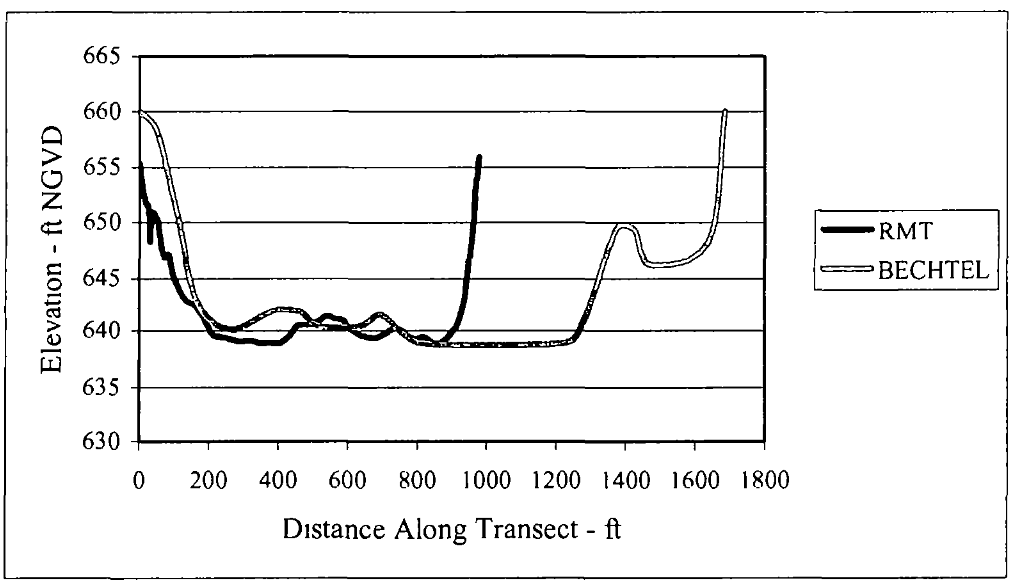


Figure A6. Transect M comparison

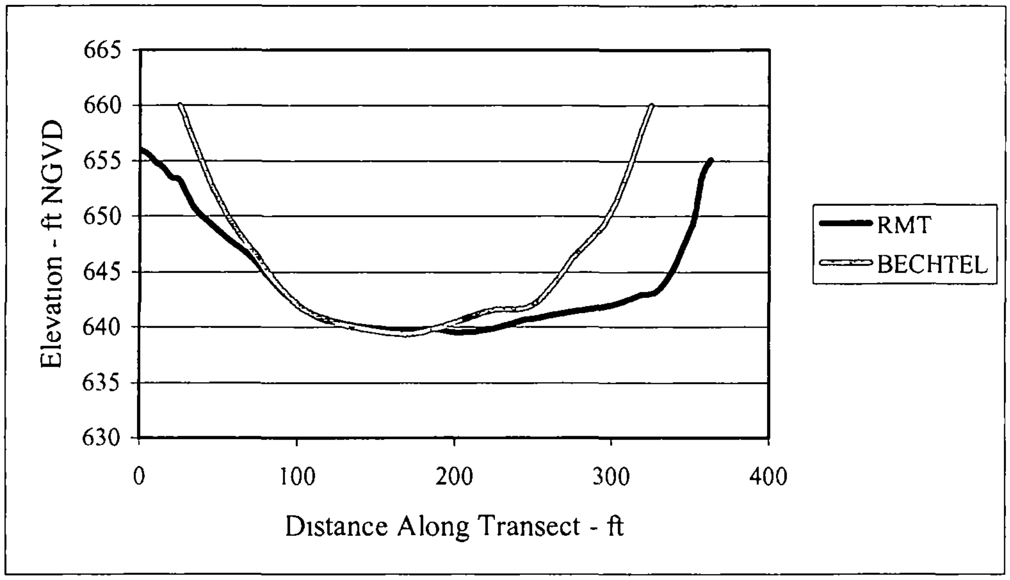


Figure A7 Transect N comparison

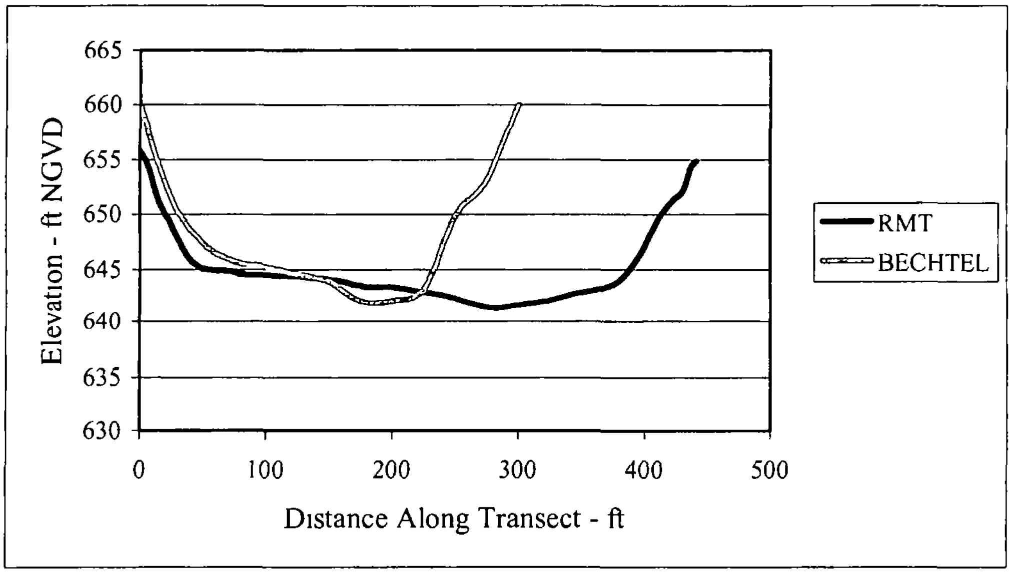


Figure A8 Transect O comparison

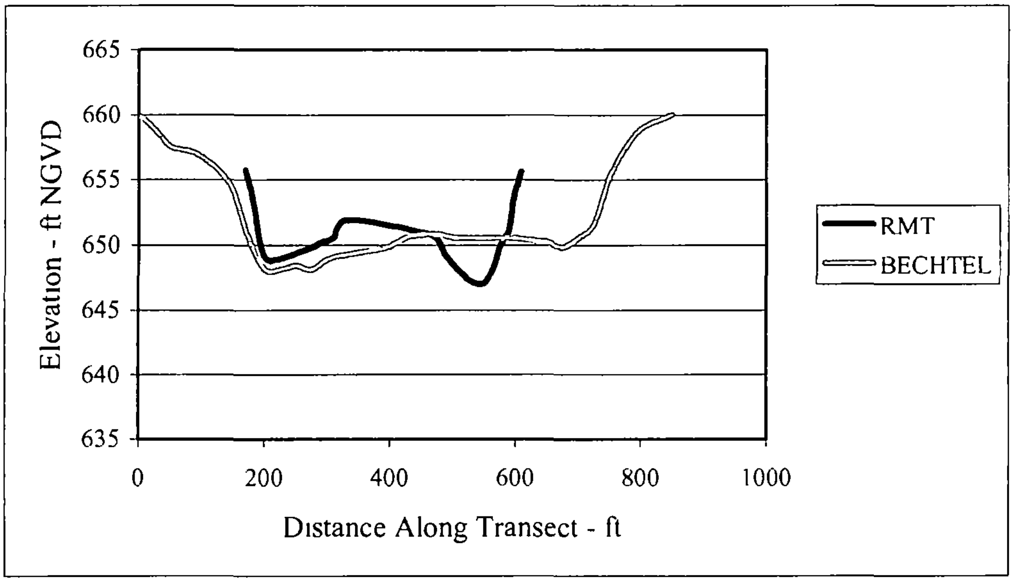


Figure A9. Transect P comparison

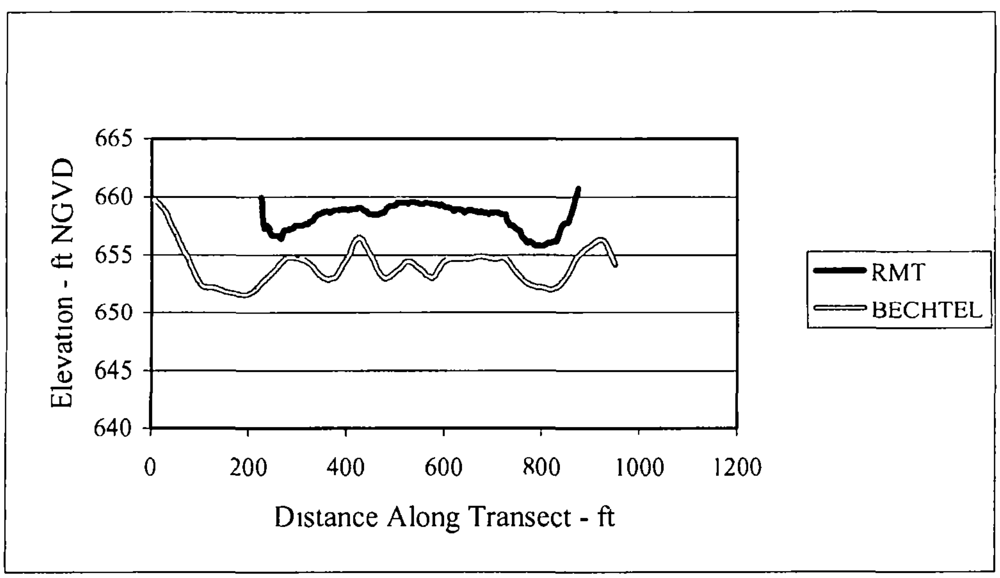


Figure A10 Transect Q comparison

APPENDIX D

Bed Sample Particle Size Distributions

BED SAMPLE DESIGNATION
LAKE HARTWELL LOWER 12 MILE CREEK

Note: HB samples collected by WES during site investigation
BS samples collected by RMT

Samples designations (left bank, center, right bank) defined for upstream view

HB1 - Maw bridge bar sample (bar on left bank, just upstream of bridge) 1"-8" depth

HB2 - Maw bridge bar sample (bar on left bank, just upstream of bridge) 8"-1' depth

HB3- Maw bridge bar sample (bar on left bank, just upstream of bridge) 2 0' depth

HB4 - 100 yards above Maw bridge in channel center

HB5 - 10 yard below lay bridge (T18) from bar off left bank

HB6 - Bar below just pipeline discharge 40 yards above Lay Bridge (T18)

HB7 - North bank T18 (Lay bridge, 0-2")

HB8 - Center T18 (Lay bridge, 0-2")

HB9 - Southbank T18 (Lay bridge, 0-2")

BS1A - Left bank above USGS gauging station (Liberty bridge)

BS1 - Channel center above USGS gagging station (Liberty bridge)

BS2A - Left bank at USGS gauging station (Liberty bridge)

BS2 - Channel center at USGS gauging station (Liberty bridge)

BS2B - Right bank at USGS gauging station (Liberty bridge)

BS3A - Left bank below USGS gauging station (Liberty bridge)

BS3 - Channel center below USGS gauging station (Liberty bridge)

BS3B - Right bank below USGS gauging station (Liberty bridge)

BS4A - Left bank upstream of Easly water supply reservoir, confluence with Shoal creek

BS4 - Channel center, upstream of Easly water supply reservoir, confluence with Shoal creek

BS4B - Right bank upstream of Easly water supply reservoir, confluence with Shoal creek

BS5A - Left bank above Woodside 1 reservoir

BS5 - Channel center above Woodside 1 reservoir

BS5B - Right bank above Woodside 1 reservoir

BS6A - Left bank above Woodside 2 reservoir

BS6 - Channel center above Woodside 2 reservoir

BS6B - Right bank above Woodside 2 reservoir

BS8A - Left bank below lay bridge, at W12 transect

BS8- Channel center below lay bridge, at W12 transect

BS8B - Right bank below lay bridge, at W12 transect

BS9A - Left bank at transect W10

BS9 - Channel center at transect W10

BS9B - Right bank at transect W10

BS10A - Left bank at transect T15 (just above Maw Bridge)

BS10 - Channel center at transect T15 (just above Maw Bridge)

BS10B - Right bank at transect T15 (just above Maw Bridge)

BS10AA - Left bank just below Maw bridge

BS10A - Channel center just below Maw bridge

BS10AB - Right bank just below Maw bridge

BS11A - Left bank at transect W7

BS11- Channel center at transect W7

BS11B - Right bank at transect W7

BS12A - Left bank between transect P and T12

BS12B - Right bank between transect P and T12

BS13A - Left bank at transect N

BS13 - Channel center at transect N

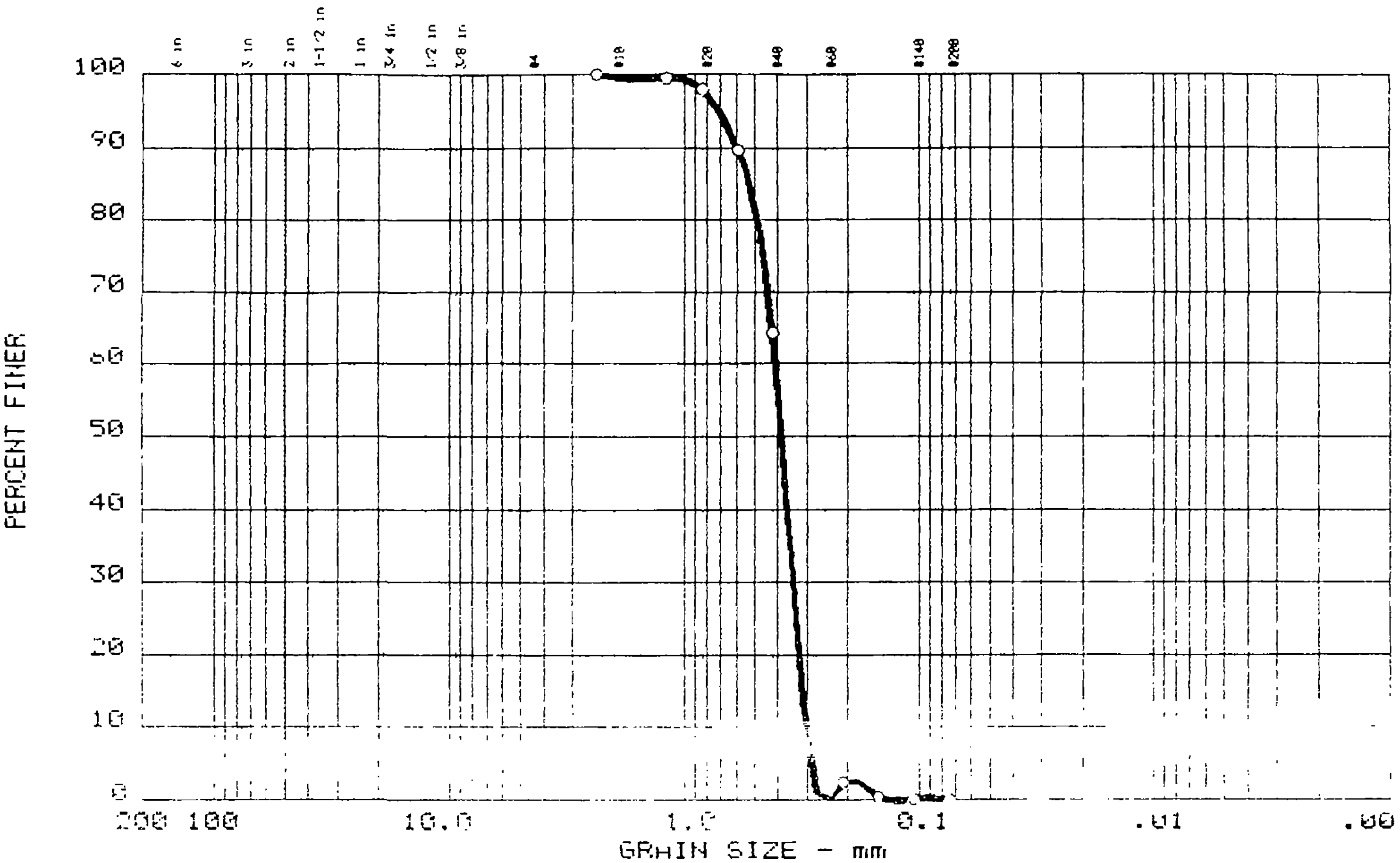
BS13B - Right bank at transect N

BS14A - Left bank at transect M

BS14 - Channel center at transect M

BS14B - Right bank at transect M

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	100.0	0.0

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.52	0.41	0.39	0.346	0.3166	0.3051	0.96	1.3

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY

○ Boring No.: HB-1

Date: 09-21-99

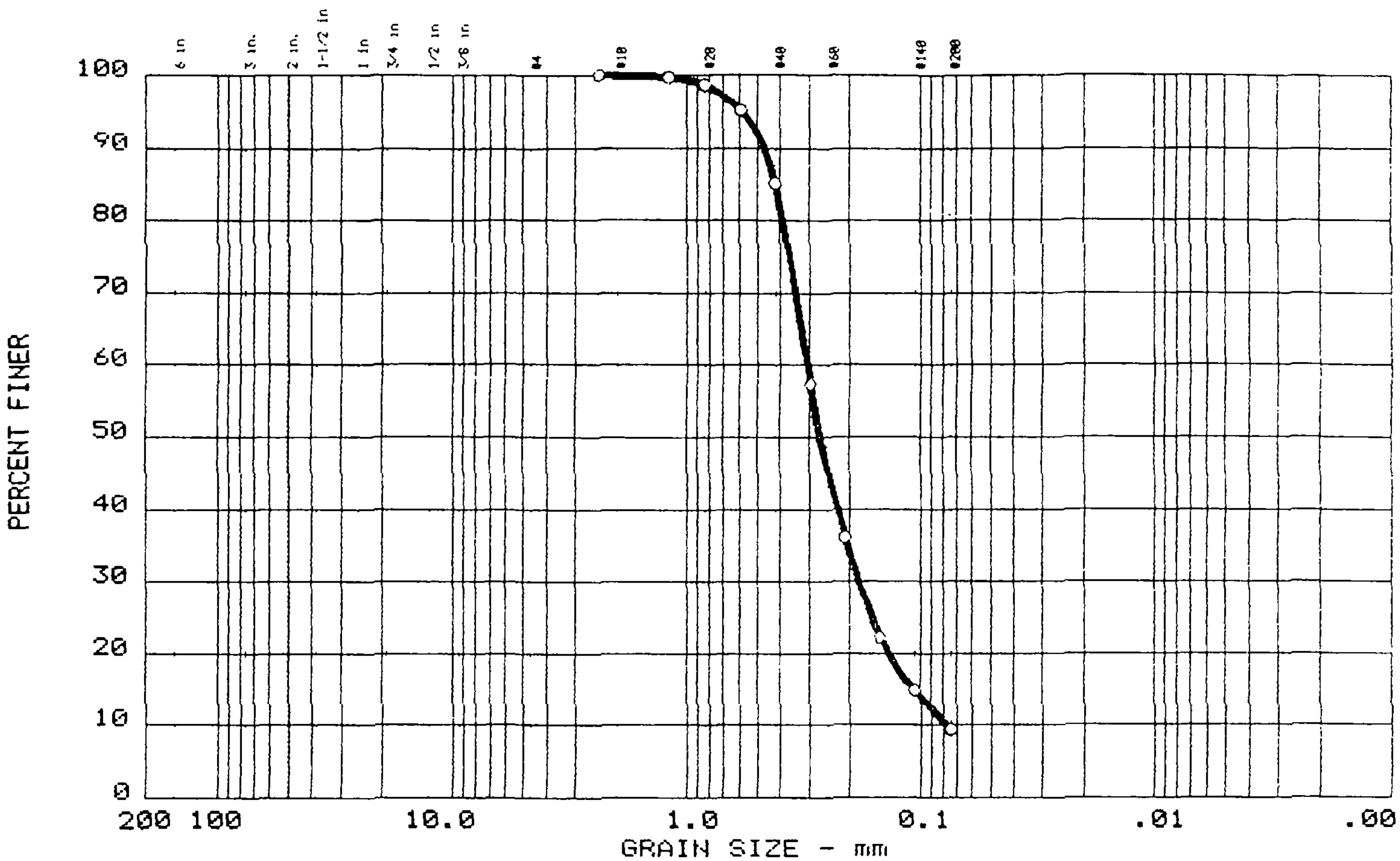
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	90.5	9.5

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.42	0.31	0.27	0.183	0.1054	0.0764	1.44	4.0

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ SP-SM	SP-SM	1	

Project: LAKE HARTWELL STUDY

○ Boring No.: HB-2

Date: 09-21-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

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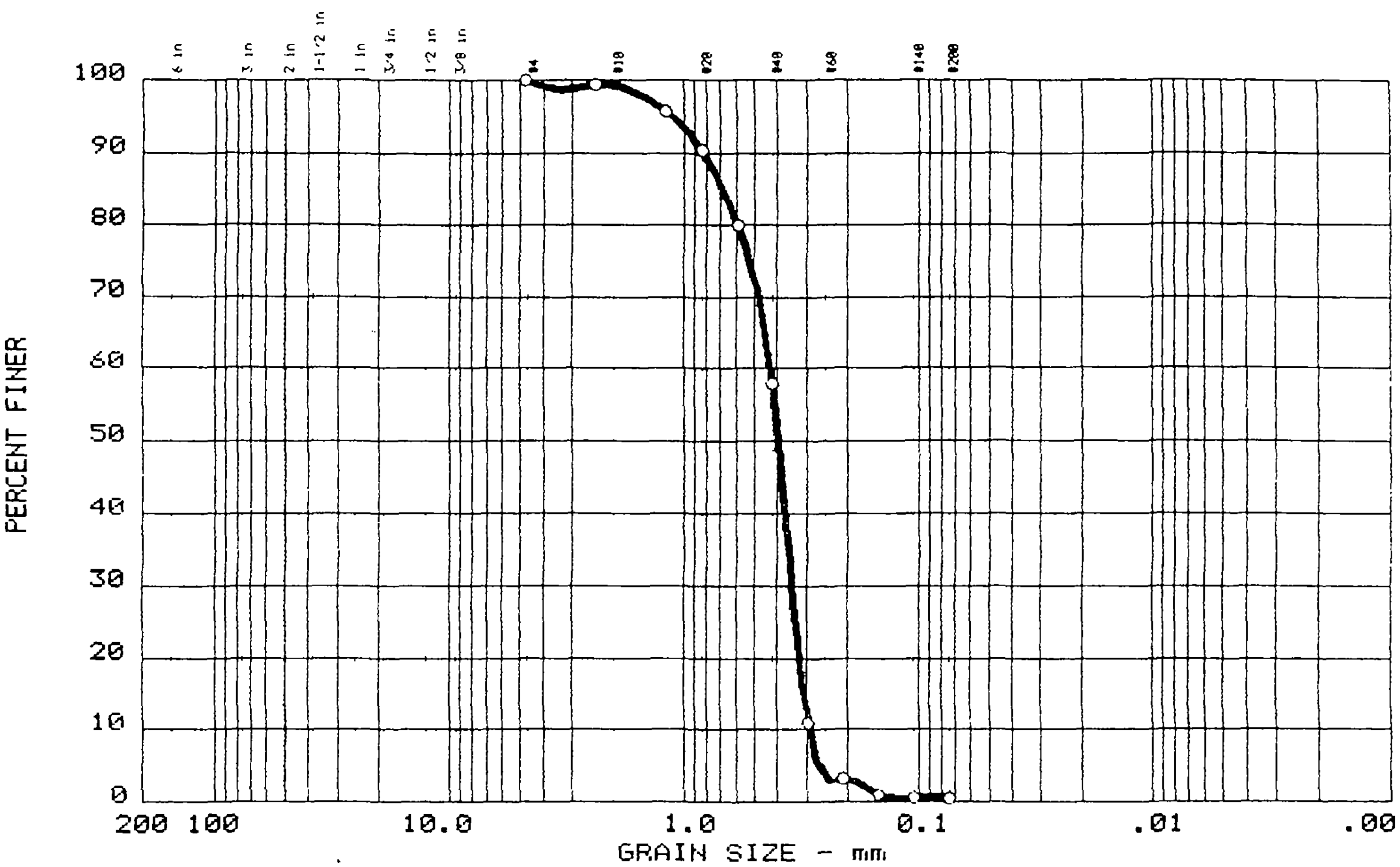

	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	99.5	0.5

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.68	0.43	0.39	0.346	0.3090	0.2938	0.95	1.5

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: HB-3

Date: 09-21-99

Remarks:

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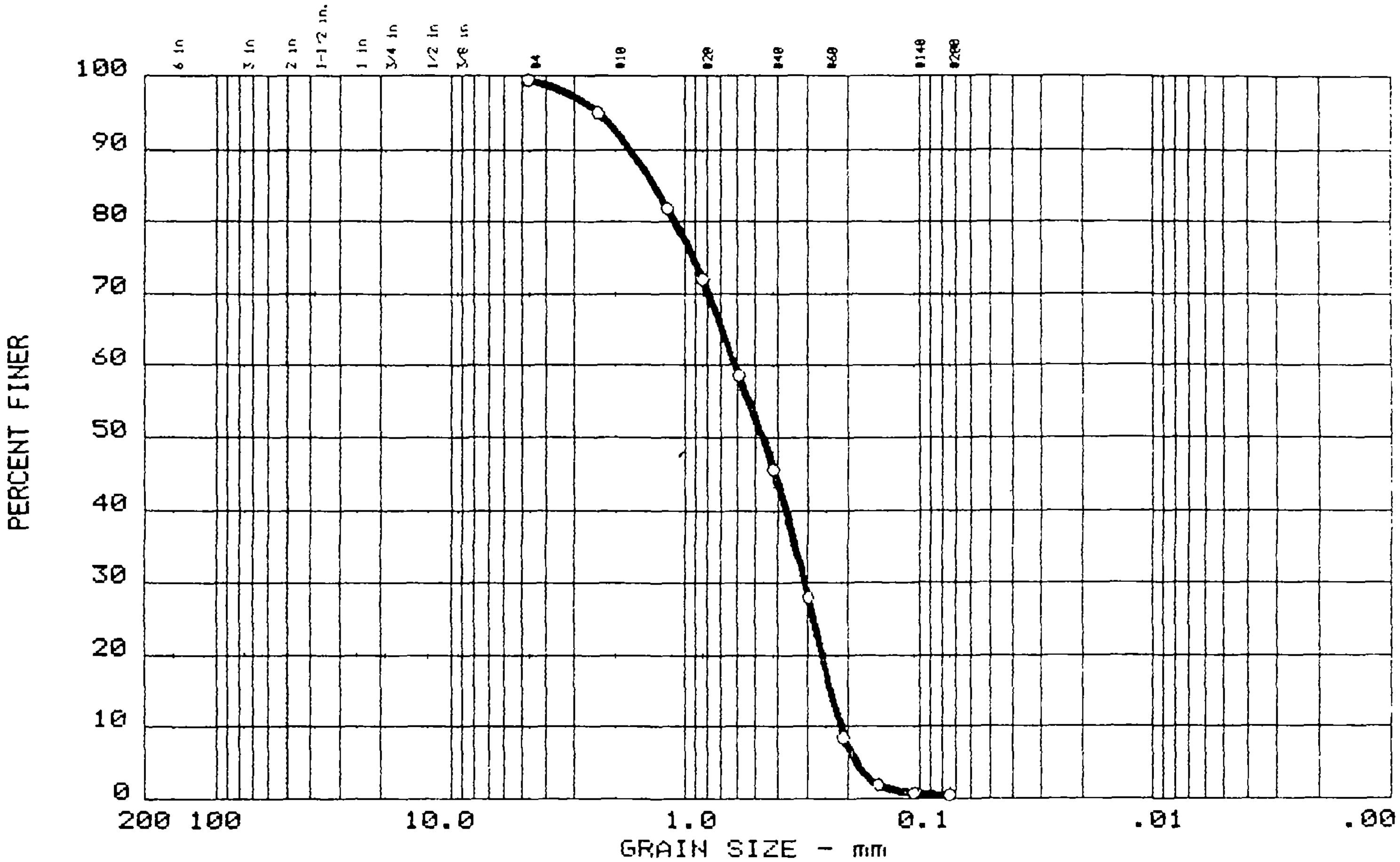
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.6	99.0	0.5

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.35	0.61	0.47	0.307	0.2396	0.2173	0.71	2.8

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: HB-4

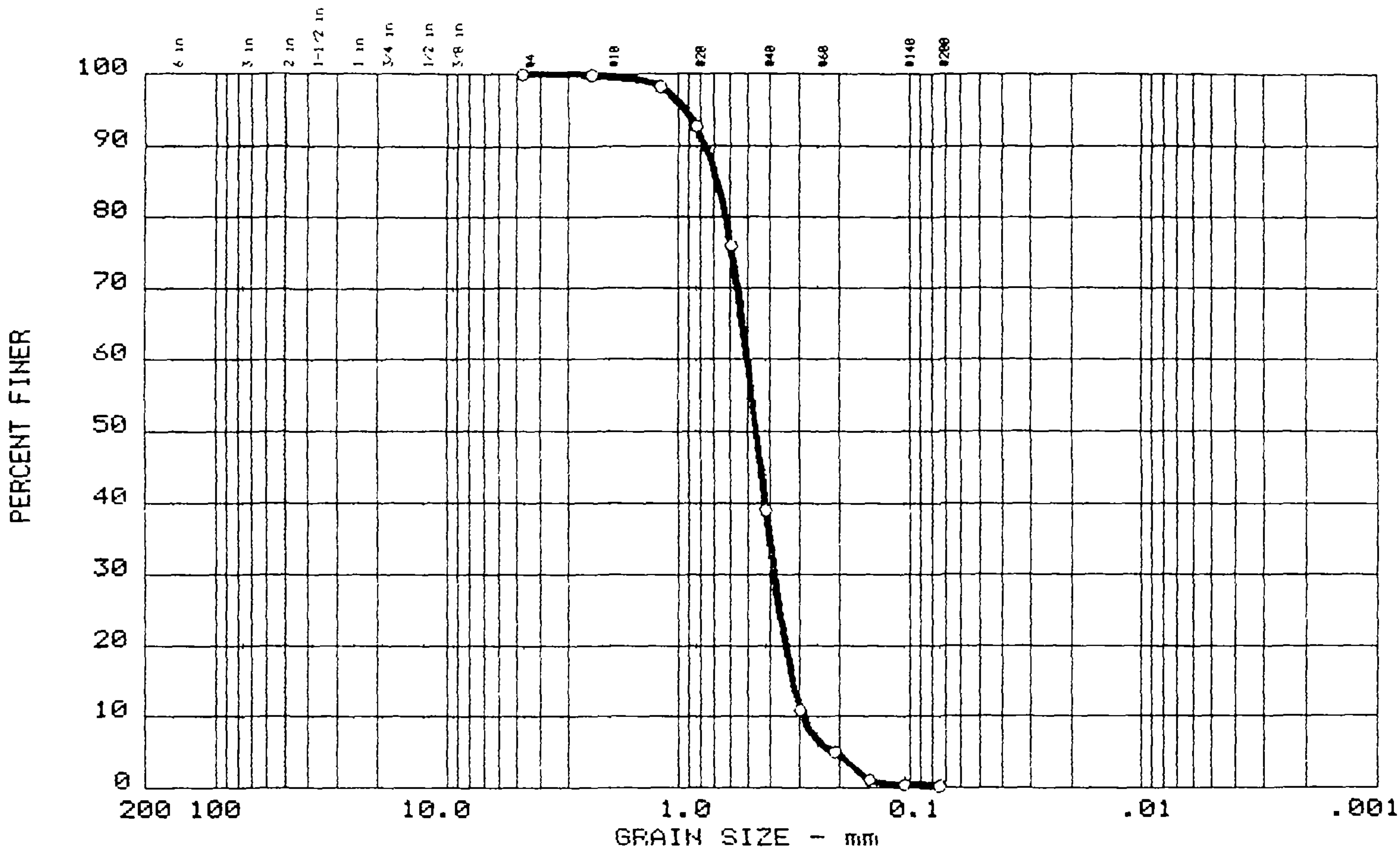
Date: 09-21-99

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	99.8	0.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.68	0.50	0.46	0.385	0.3203	0.2904	1.01	1.7

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: HB-5

Date: 09-21-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

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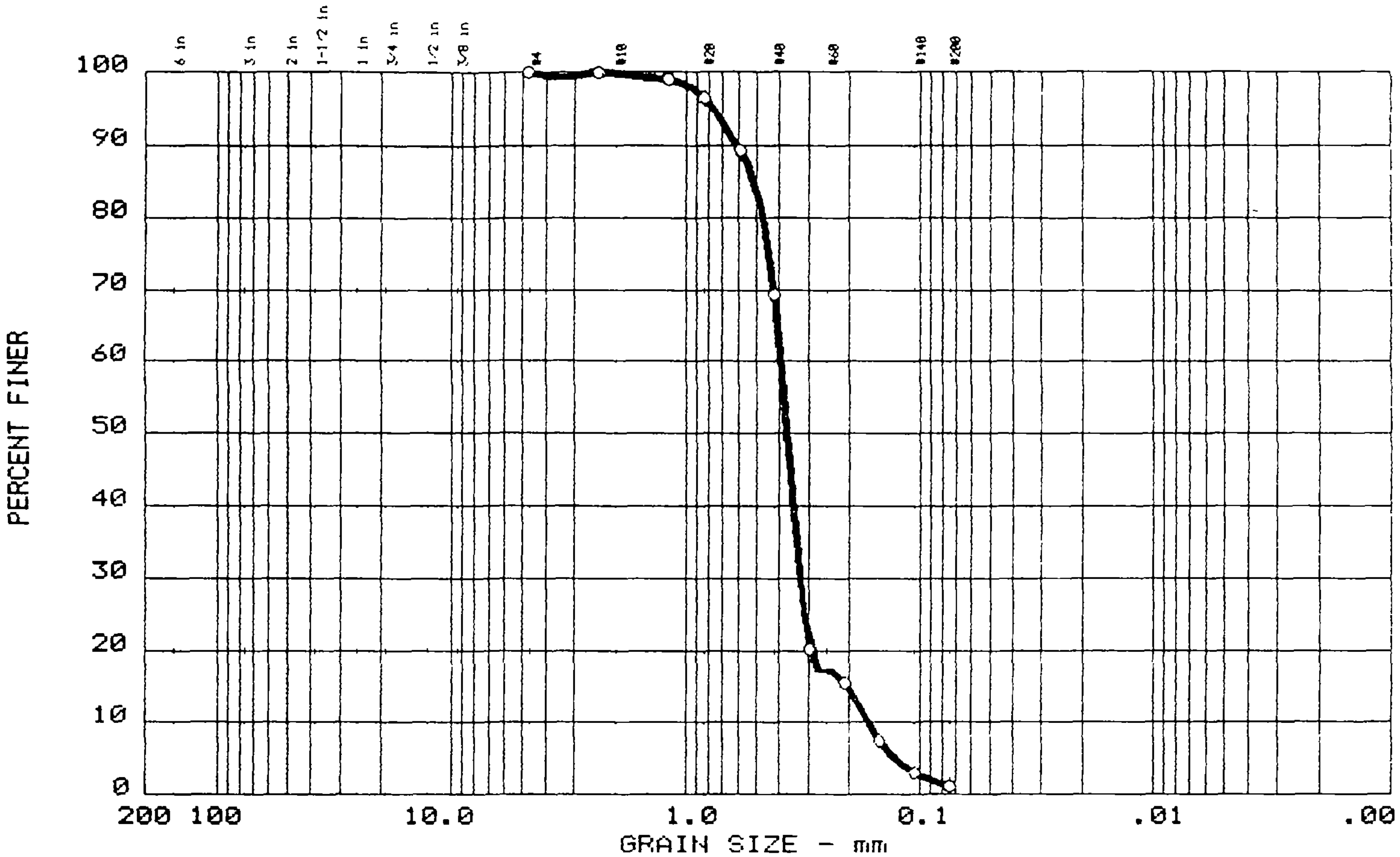
GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES	
○	0.0	0.0	98.9	13.4	-12.3

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.51	0.39	0.37	0.326	0.2035	0.1654	1.63	2.4

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: HB-6

Date: 09-21-99

Remarks:

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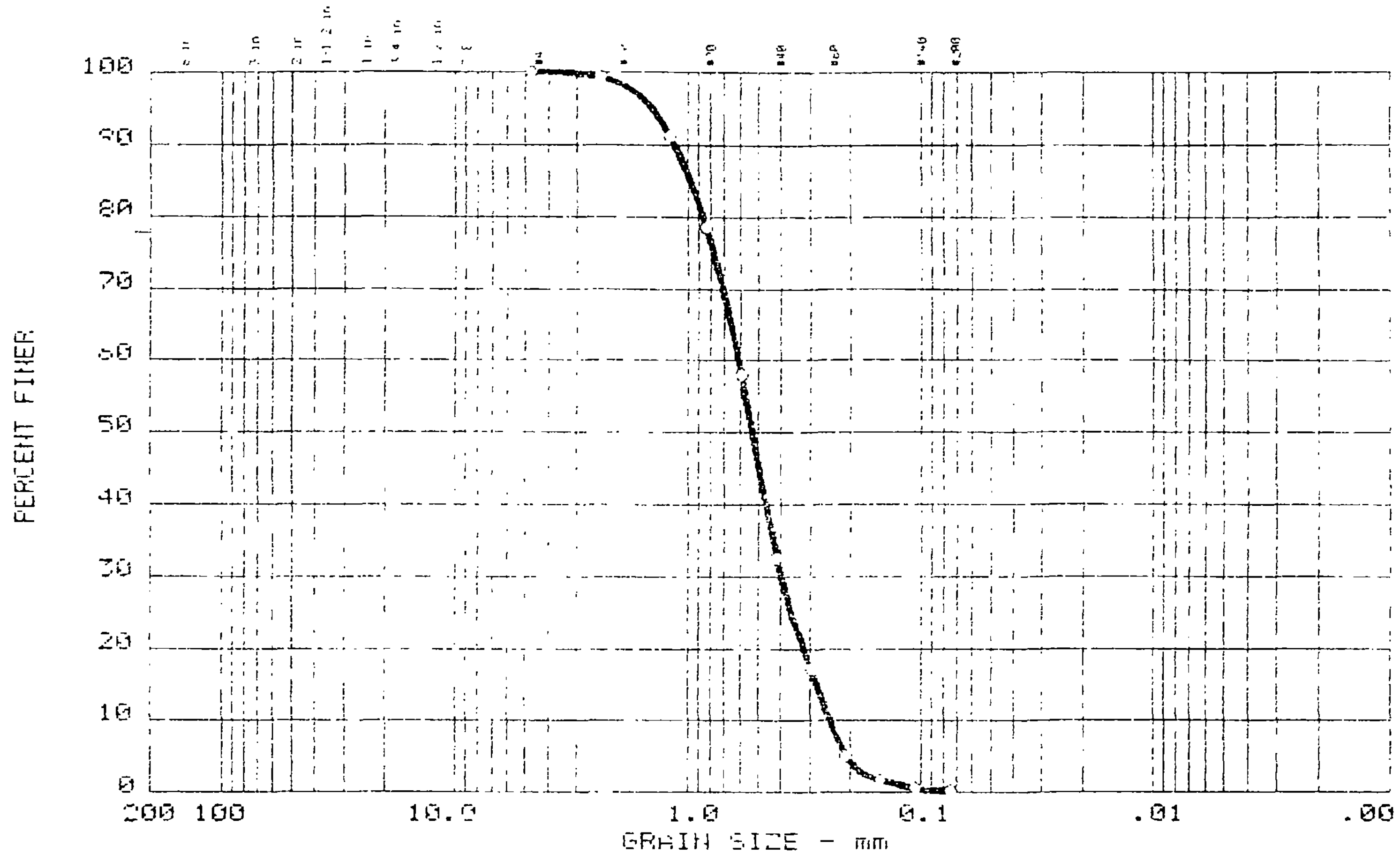
Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	99.8	0.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.98	0.61	0.53	0.402	0.2796	0.2460	1.08	2.5

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE [illegible]

Boring No.: HE-7 T-18 N. BANK

Date: 09-20-99

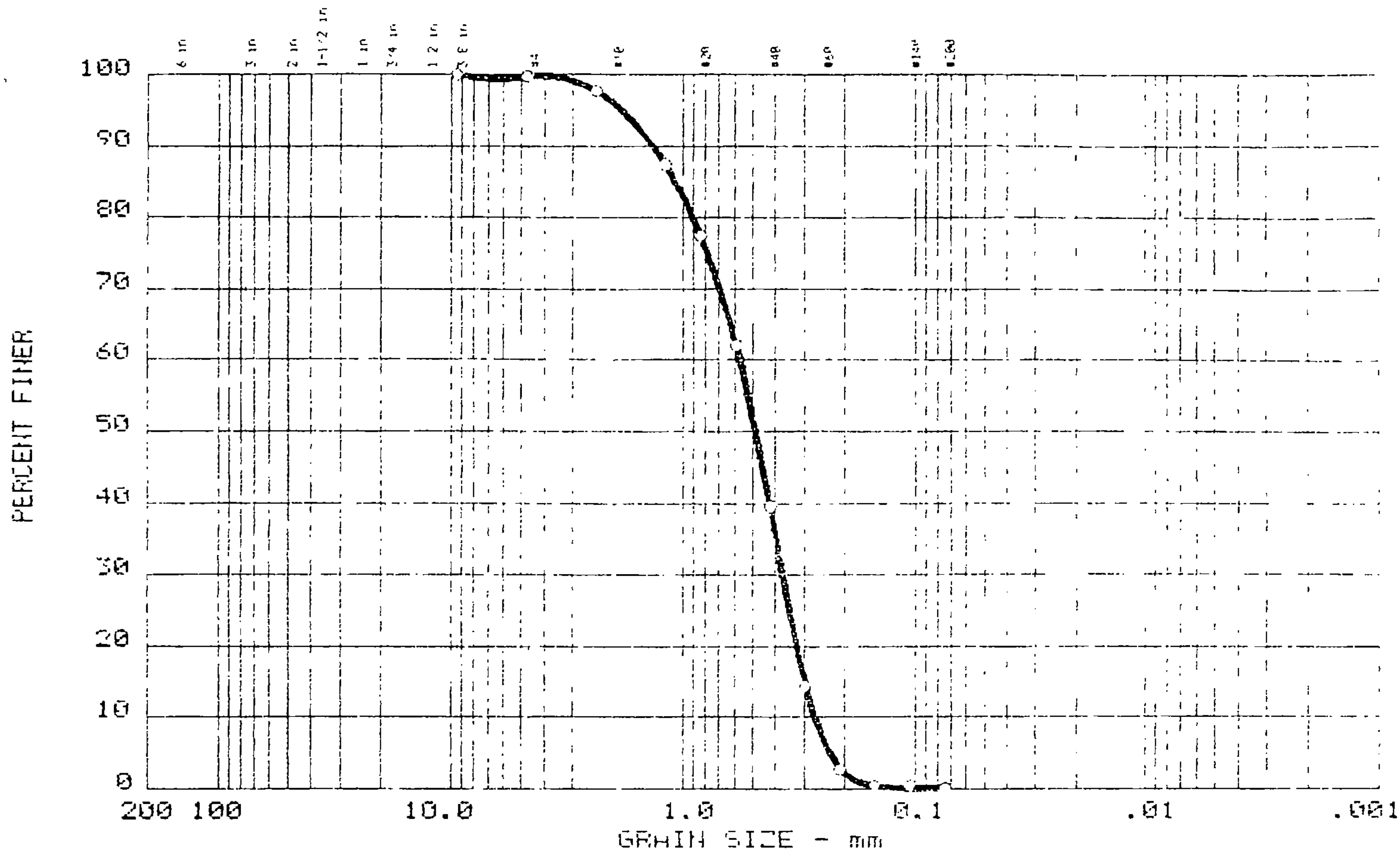
Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. _____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.3	99.6	0.1

LL	PL	NWC	D85	D60	D50	D30	D15	D10	Cc	Cu
			1.07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY

○ Boring No.: HB-8 T18 CENTER BI

Date: 09-21-99

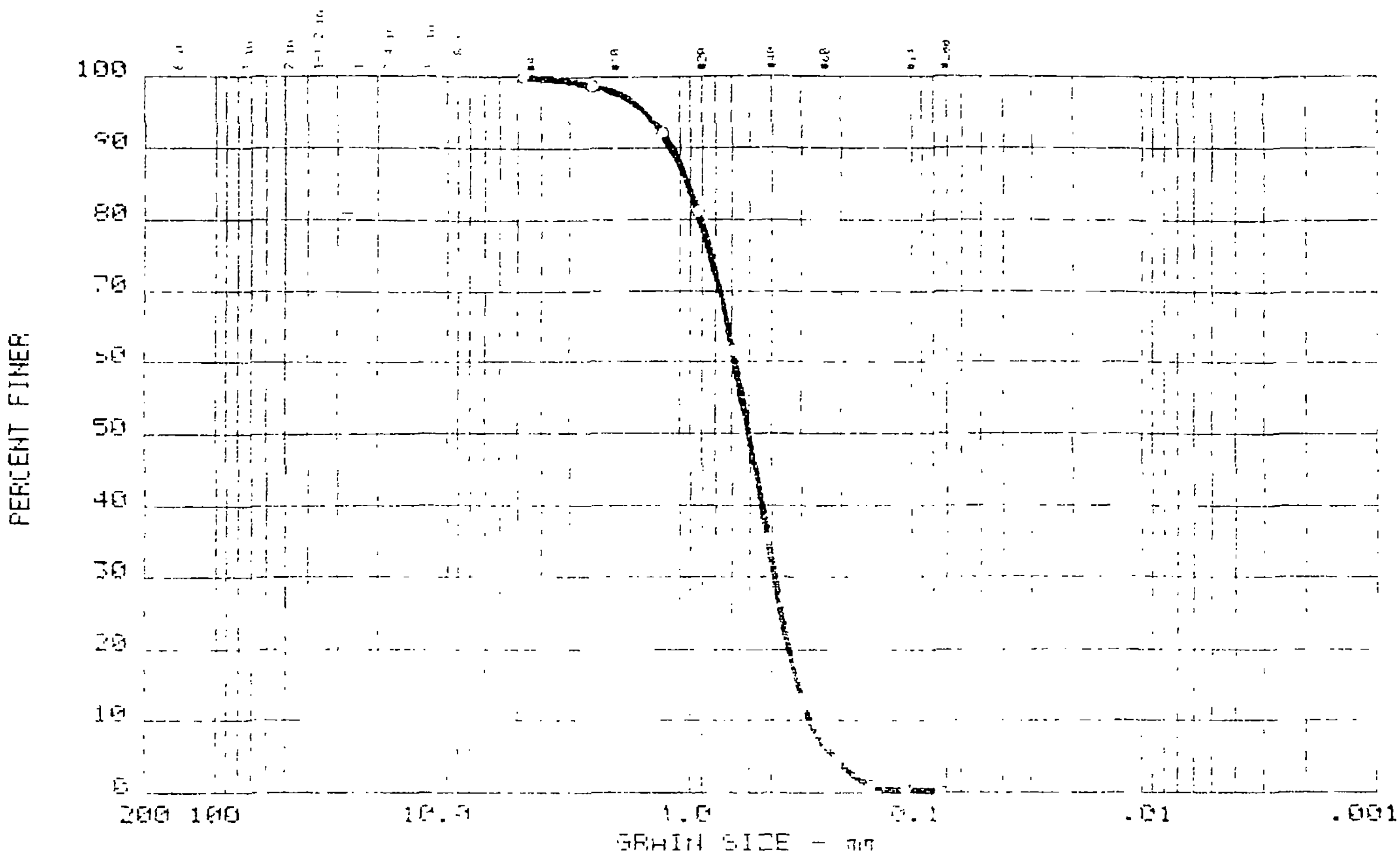
Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No.

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	99.9	0.1

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.91	0.58	0.50	0.392	0.3094	0.2726	0.98	2.1

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Remarks:

Project: LAKE HARTWELL STUDY
○ Boring No.: HB-9 S.B. 7-19

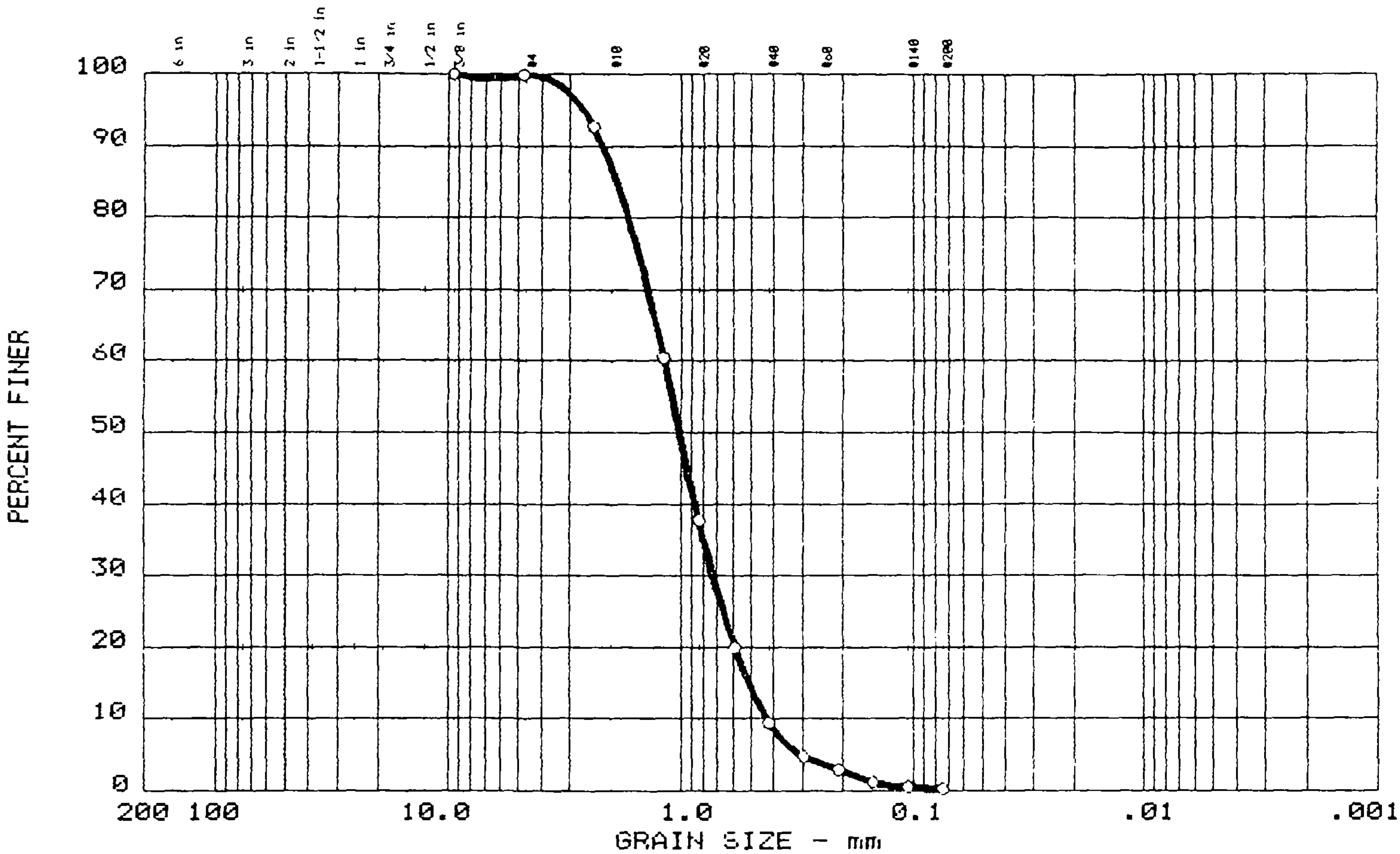
Date: 09-21-95

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.2	99.6	0.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.89	1.18	1.02	0.733	0.5129	0.4266	1.07	2.8

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-1-A

Date: 09-21-99

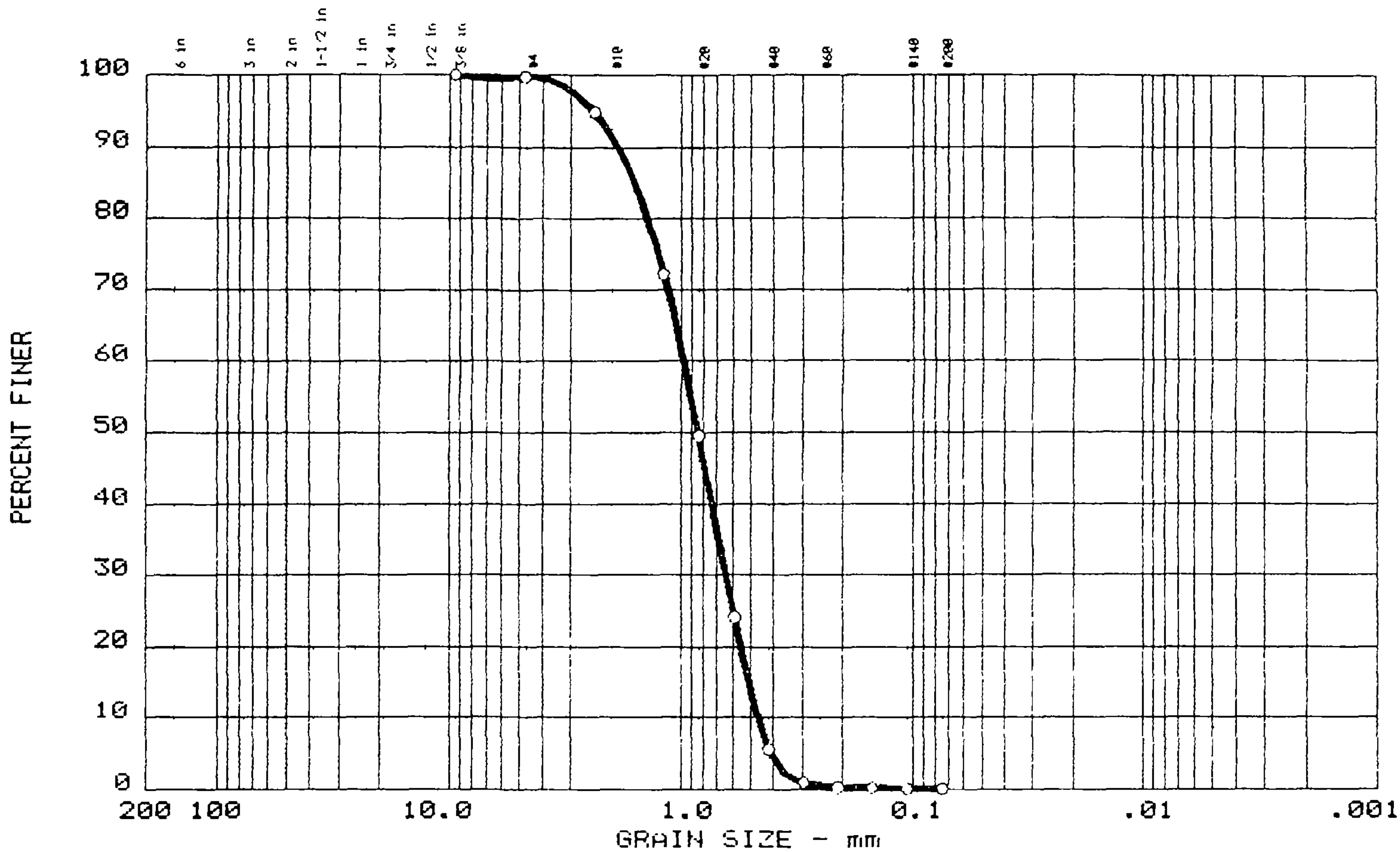
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.3	99.6	0.1

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.58	0.98	0.85	0.641	0.5117	0.4661	0.90	2.1

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-1

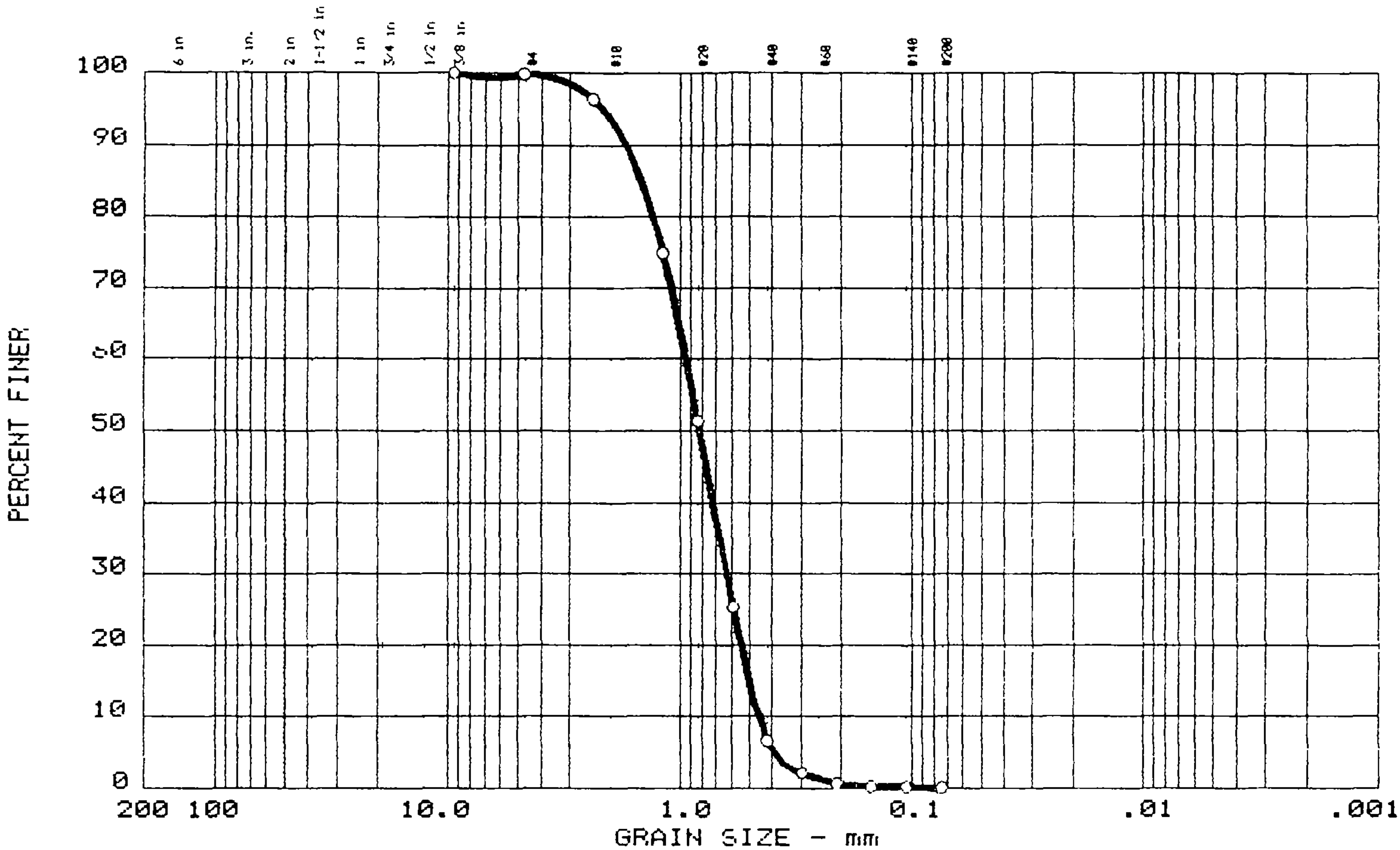
Date: 09-21-99

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.2	99.7	0.1

	LL	PL	NMC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.48	0.95	0.82	0.630	0.5023	0.4571	0.92	2.1

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ M-F SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-2A

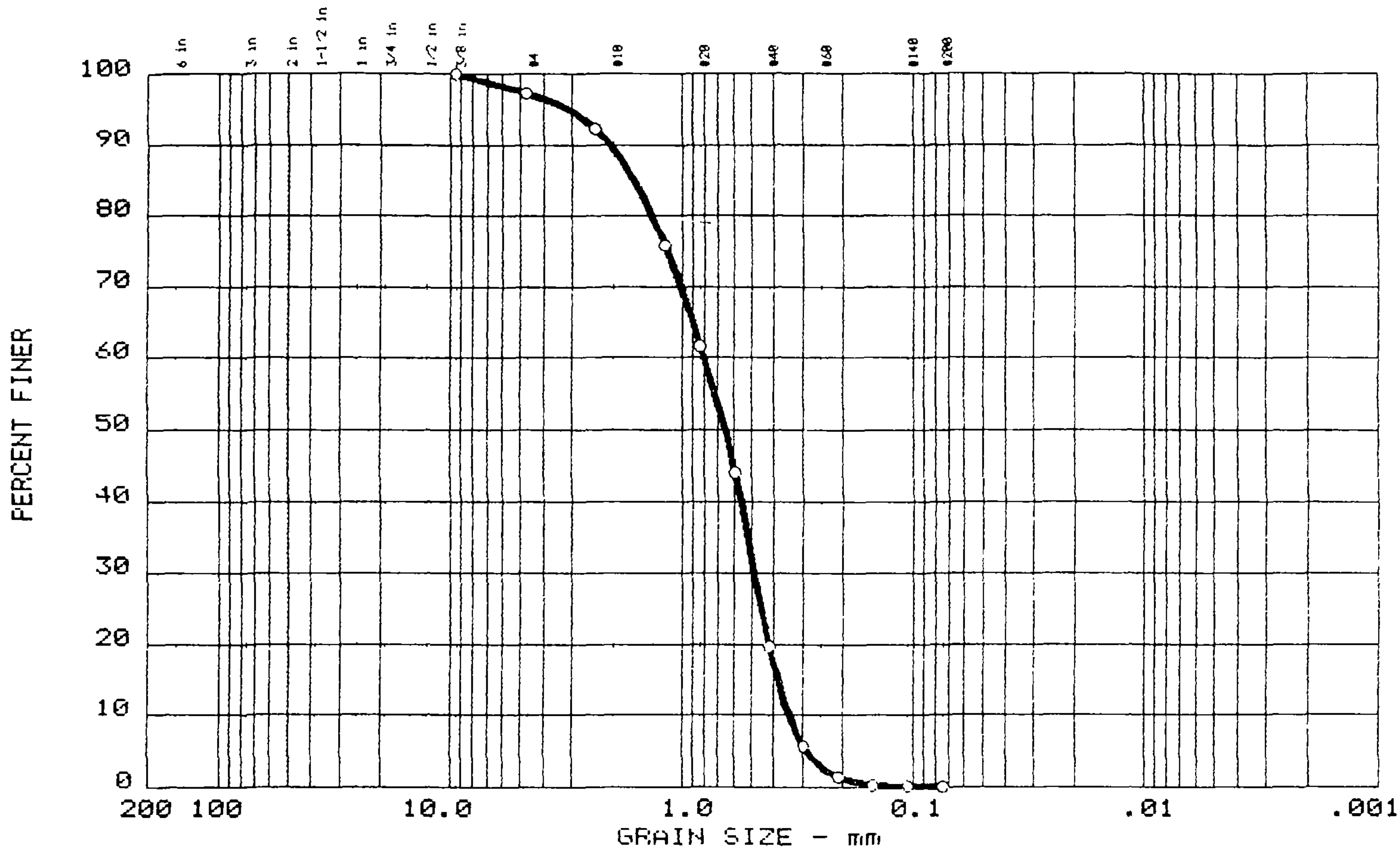
Date: 09-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. _____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	2.7	97.2	0.1

LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
			1.62	0.81	0.65	0.486	0.3959	0.3440	0.85	2.3

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP W/TR-G	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-2

Date: 09-22-99

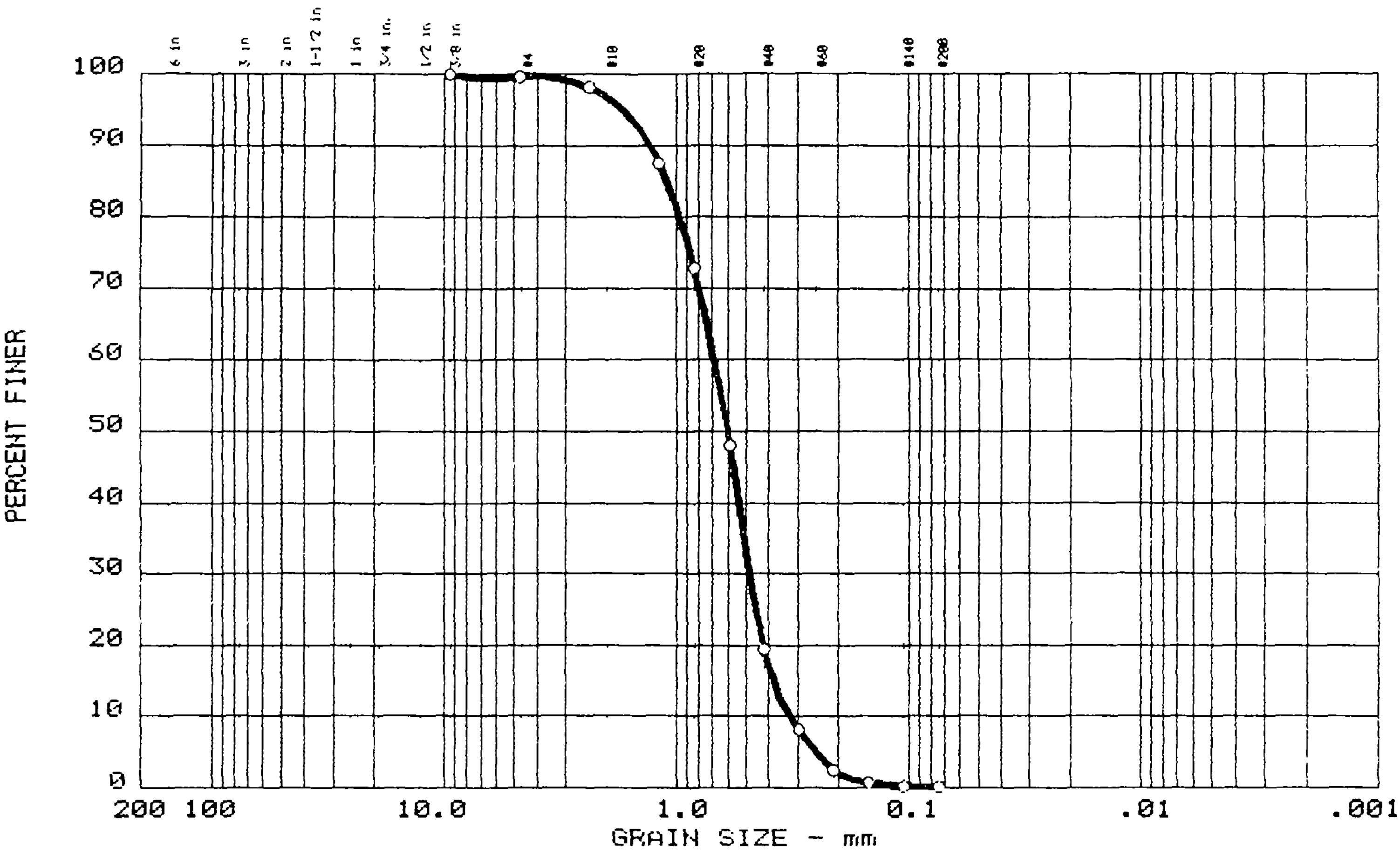
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.4	99.5	0.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.10	0.69	0.60	0.483	0.3850	0.3240	1.05	2.1

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ M-F SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS 2B

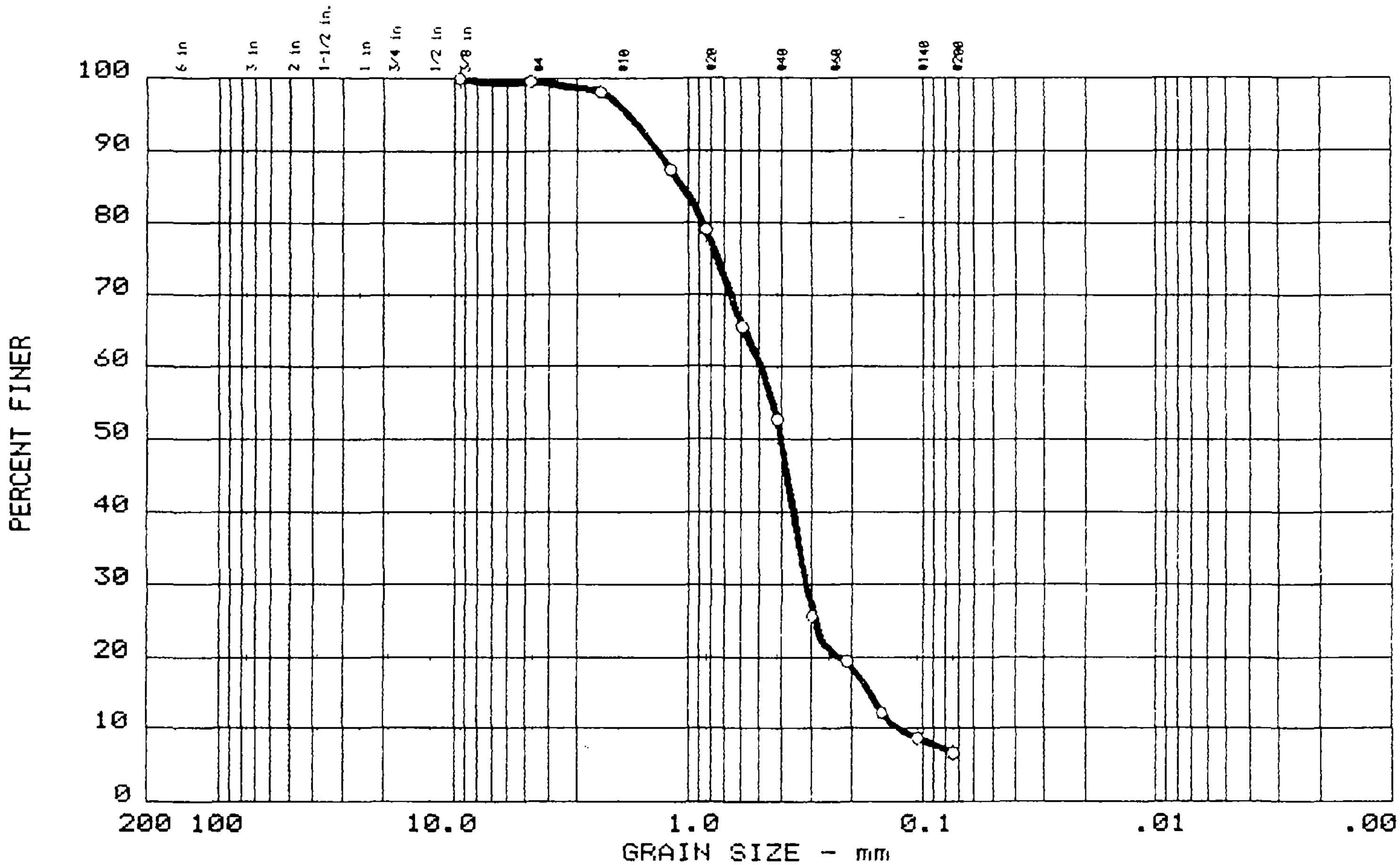
Date: 09-21-99

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.5	92.8	6.7

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.05	0.49	0.40	0.318	0.1687	0.1265	1.63	3.9

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ SP-SM	SP-SM	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS 3A

Date: 9-22-99

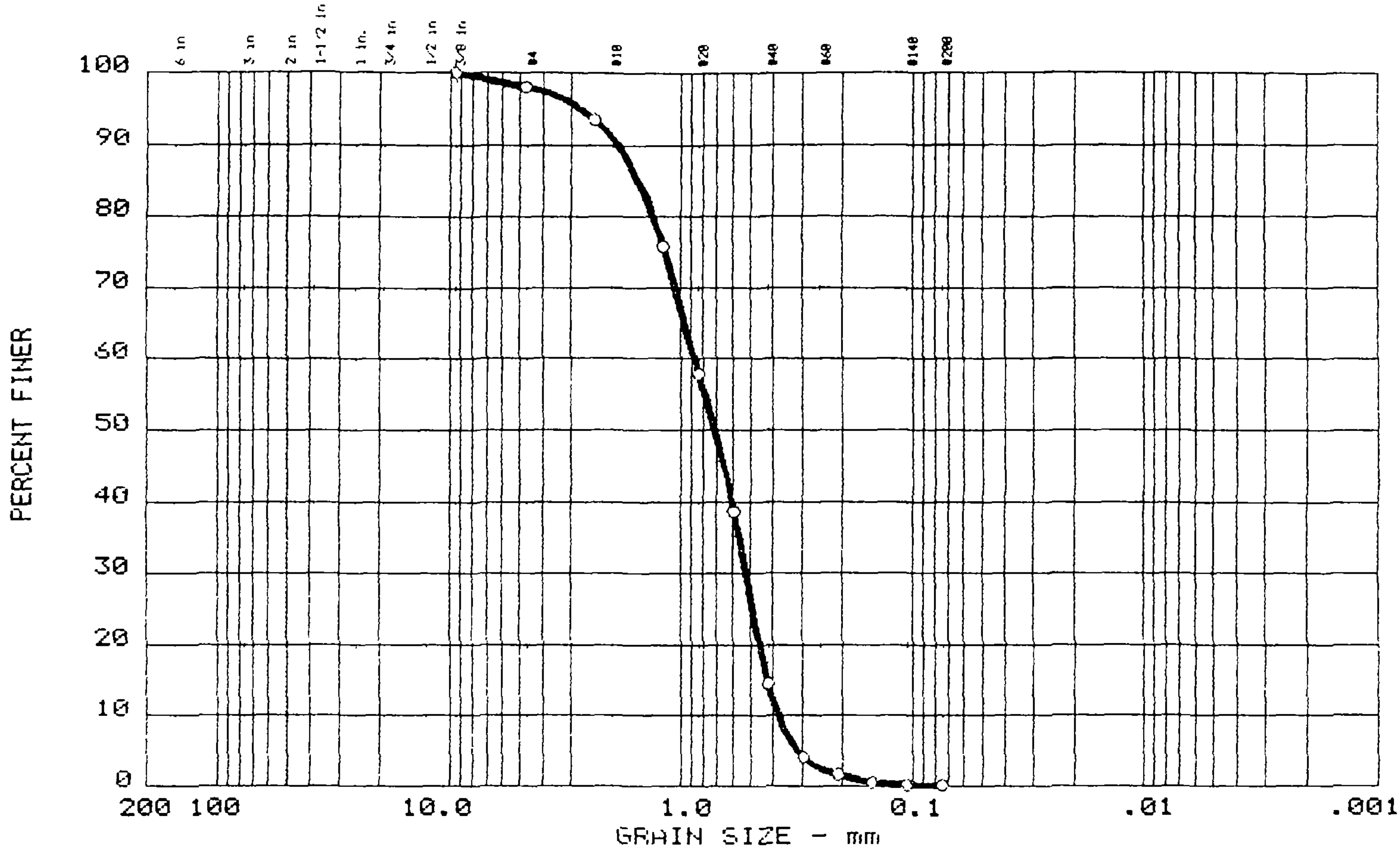
Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



% +3"	% GRAVEL	% SAND	% FINES
0.0	2.0	97.9	0.1

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.53	0.87	0.72	0.524	0.4232	0.3806	0.82	2.3

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ M-F SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-3 CENTER

Date: 9-22-99

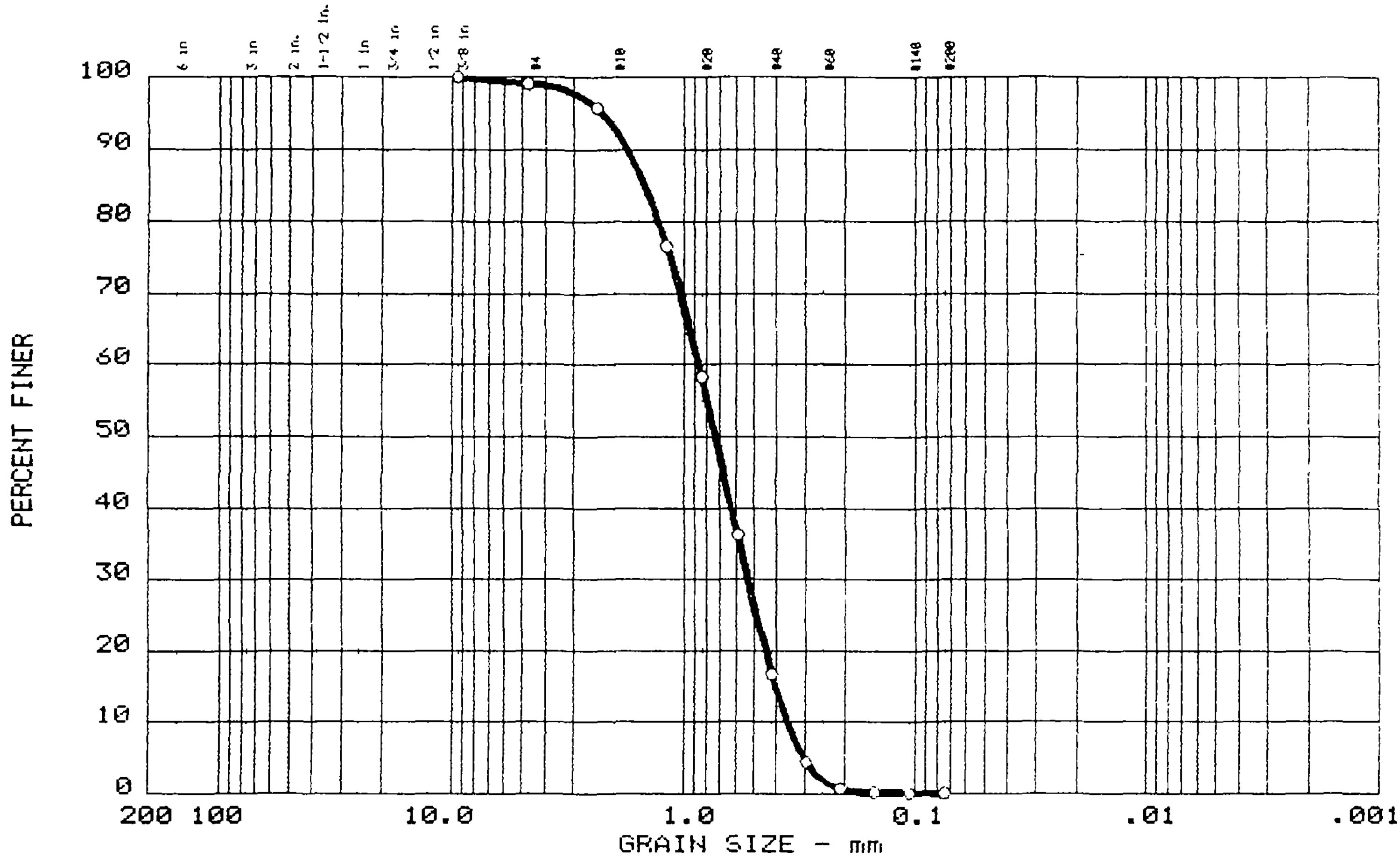
Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.9	99.0	0.1

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.48	0.86	0.73	0.533	0.4041	0.3585	0.92	2.4

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ M-F SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS 3B

Date: 09-21-99

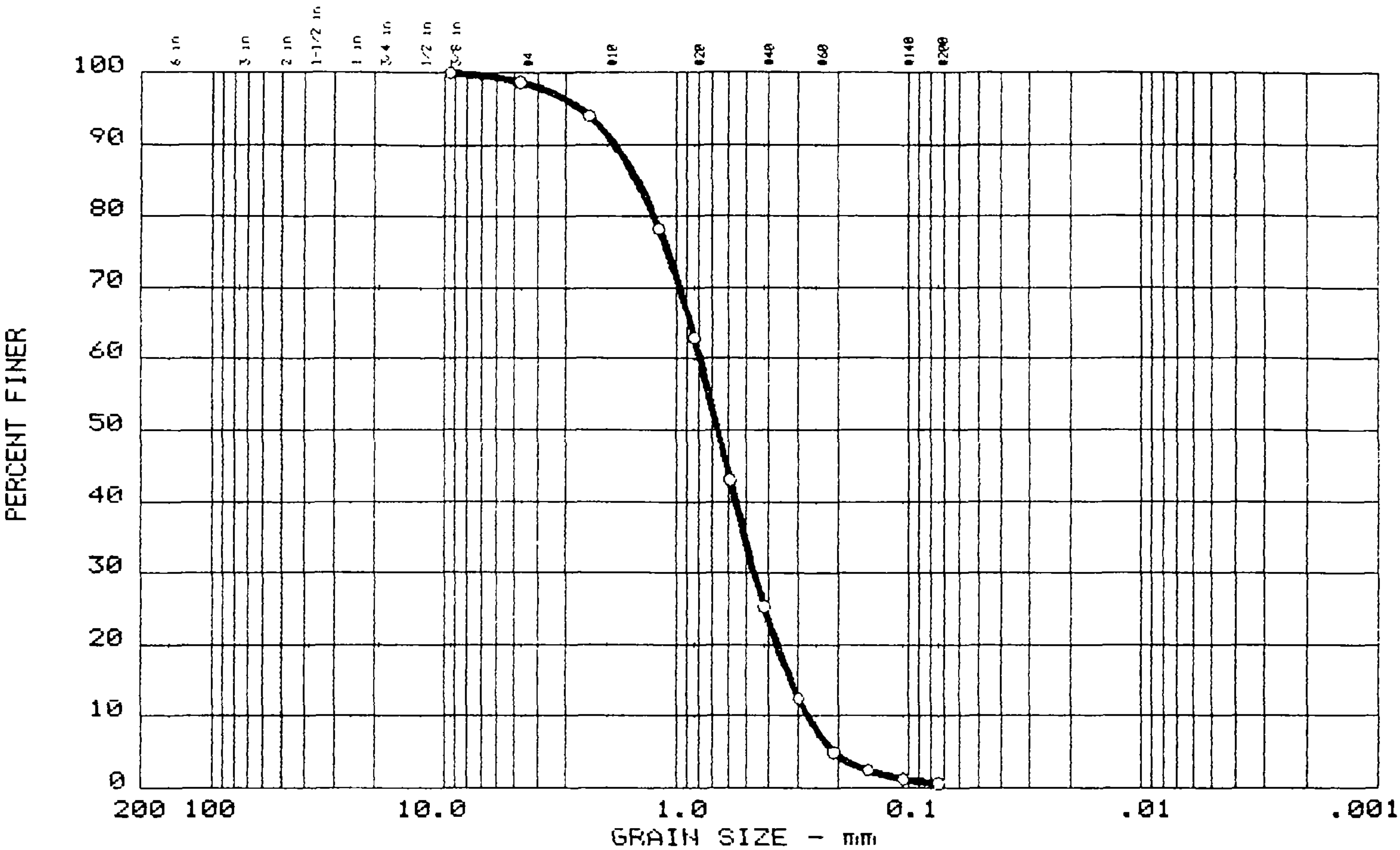
Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	1.2	98.1	0.7

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.48	0.79	0.67	0.463	0.3203	0.2716	0.99	2.9

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ M-F SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-4A

Date: 9-22-99

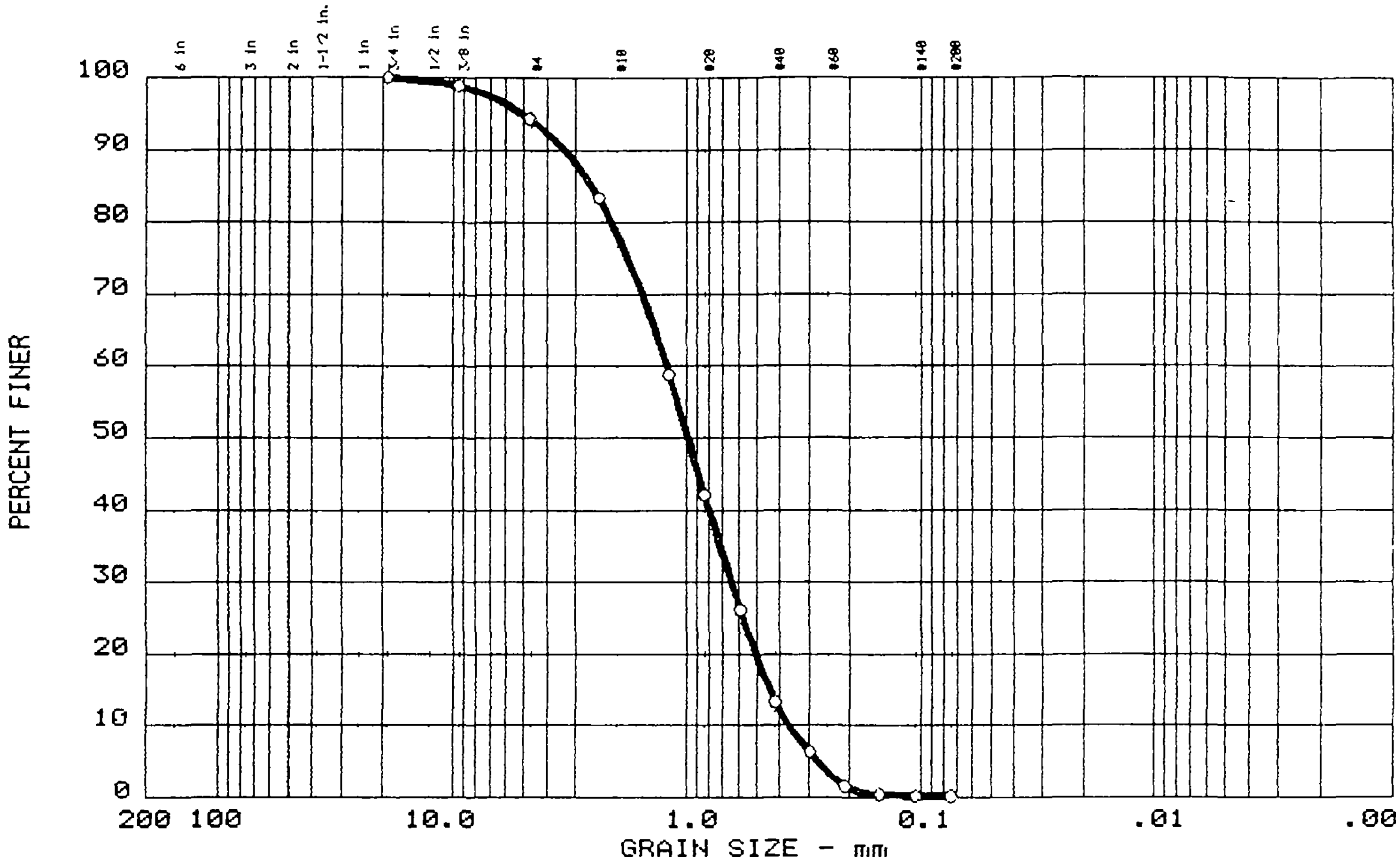
Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	5.6	94.2	0.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				2.54	1.22	0.99	0.644	0.4436	0.3648	0.94	3.3

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ C-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-4

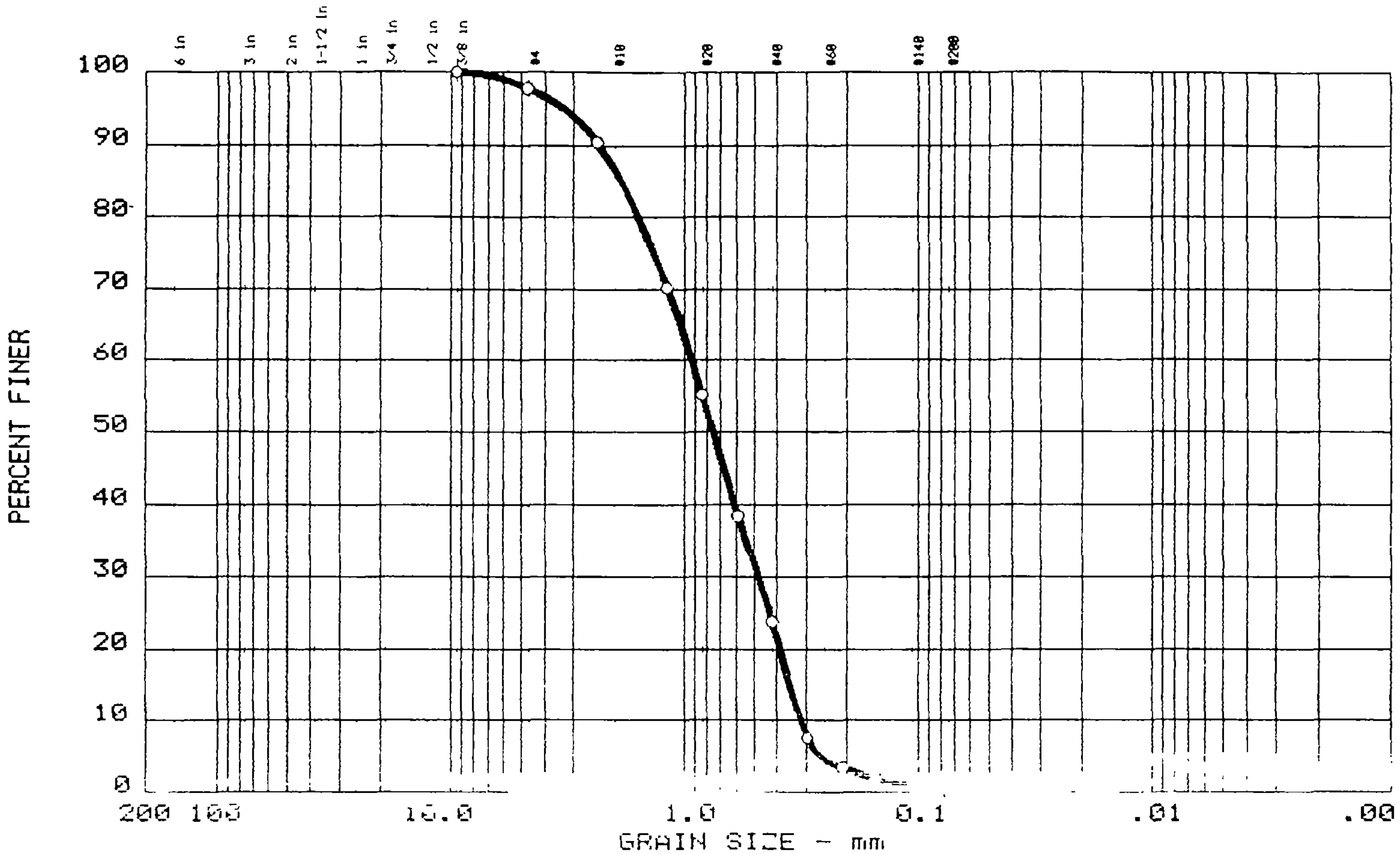
Date: 09-21-99

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	2.2	97.7	0.1

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.86	0.93	0.75	0.481	0.3524	0.3170	0.78	2.9

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ M-F SAND SP W/ TR/G	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS4B

Date: 09-21-99

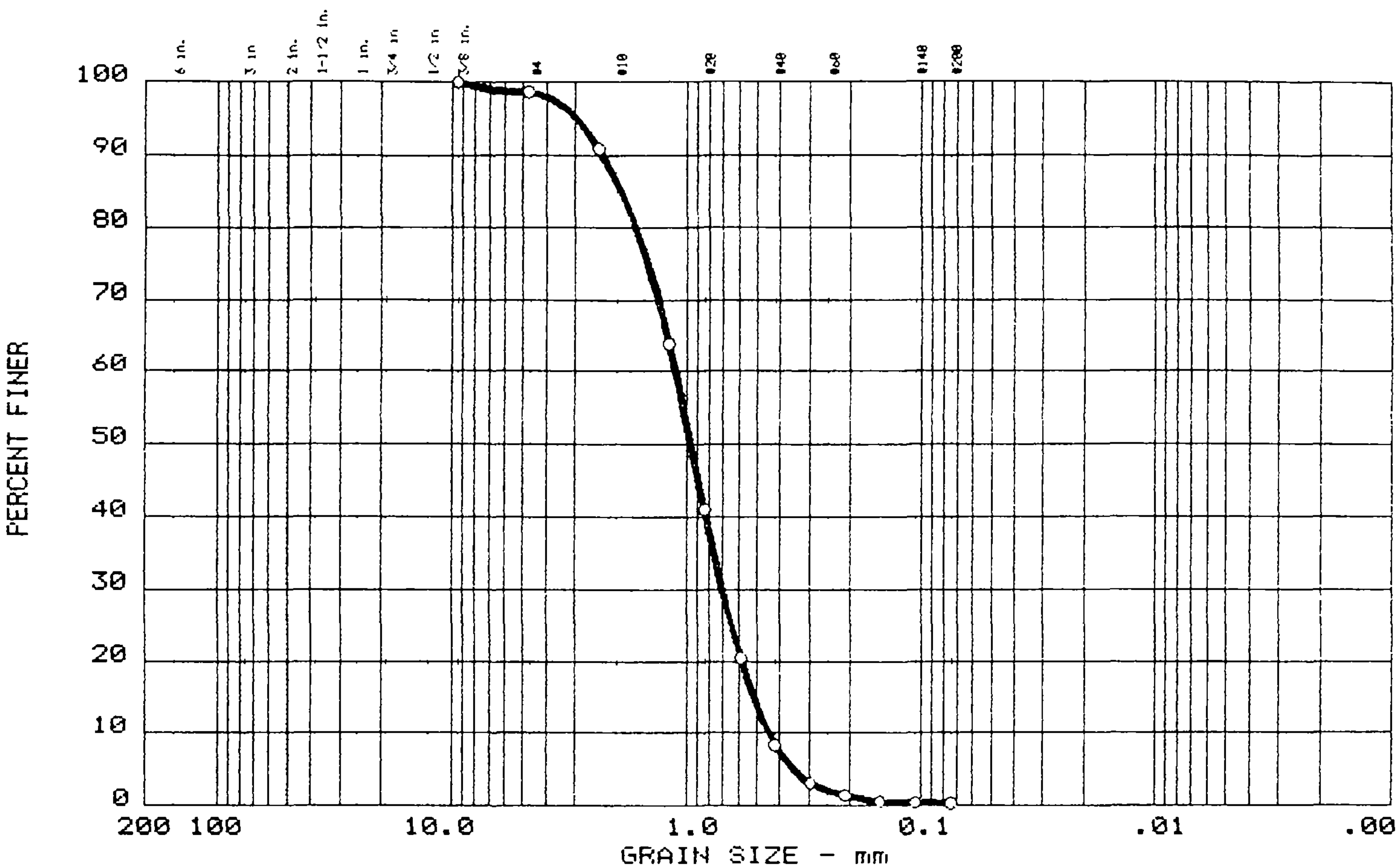
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. _____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	1.4	98.4	0.3

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.91	1.12	0.96	0.703	0.5194	0.4467	0.99	2.5

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP W/TR-G	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-5A

Date: 9-22-99

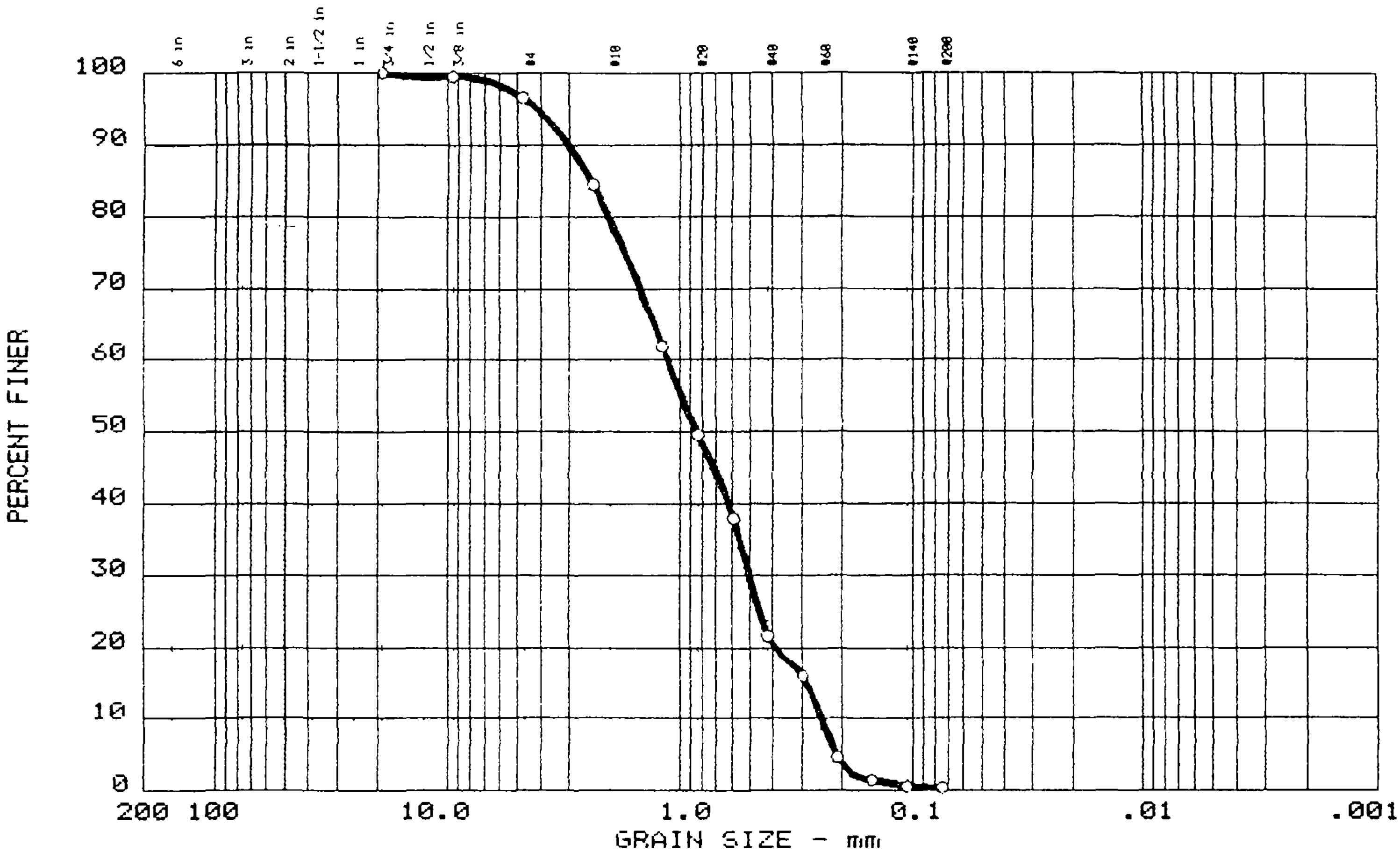
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	3.4	96.2	0.3

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				2.43	1.13	0.85	0.505	0.2841	0.2469	0.91	4.6

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP W/TR-G	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-5

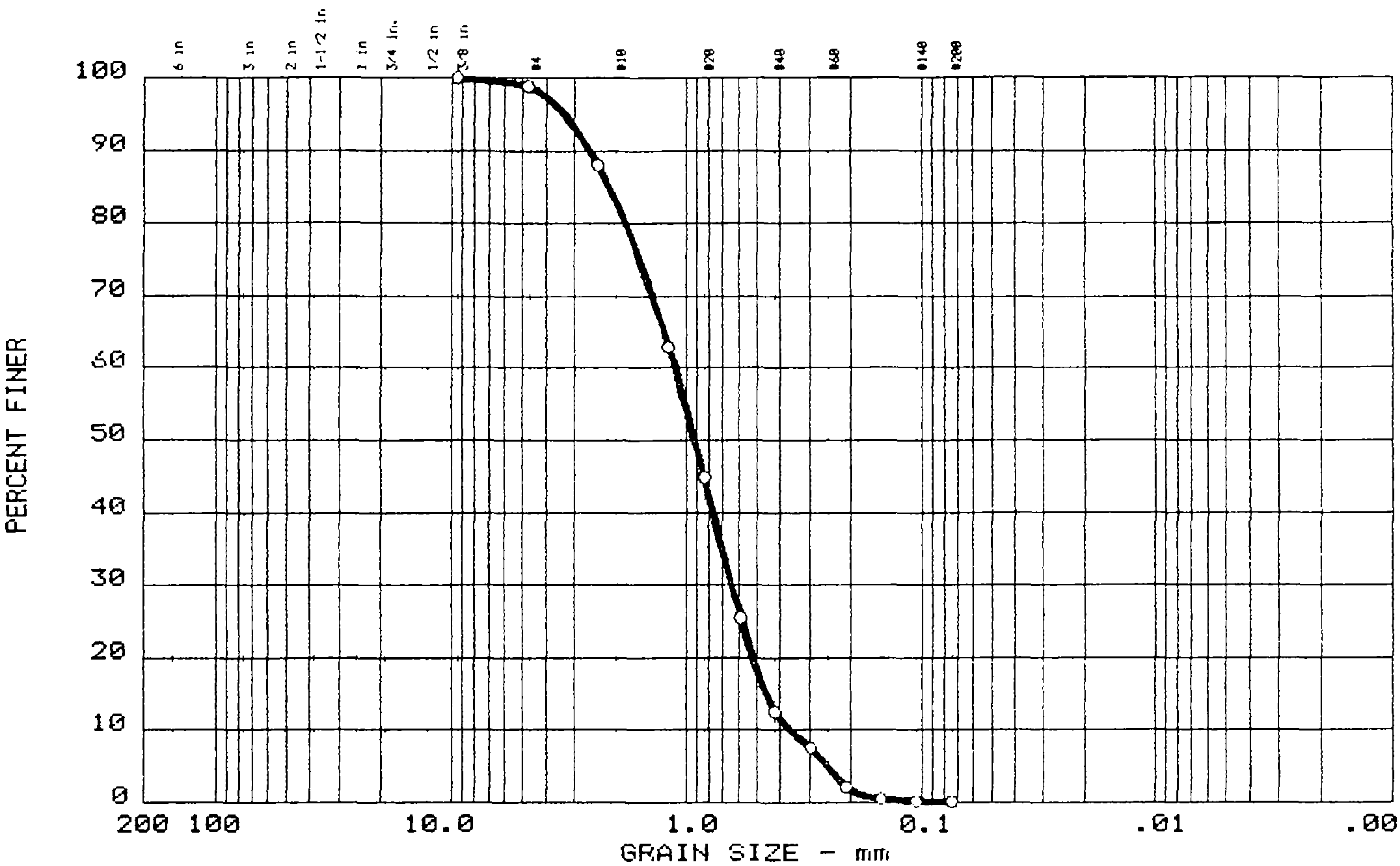
Date: 09-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. _____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	1.2	98.7	0.1

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				2.13	1.12	0.92	0.643	0.4592	0.3606	1.03	3.1

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP W/TR-G	SP	1	

Project: LAKE HARTWELL STUDY

○ Boring No.: BS-5-B

Date: 09-21-99

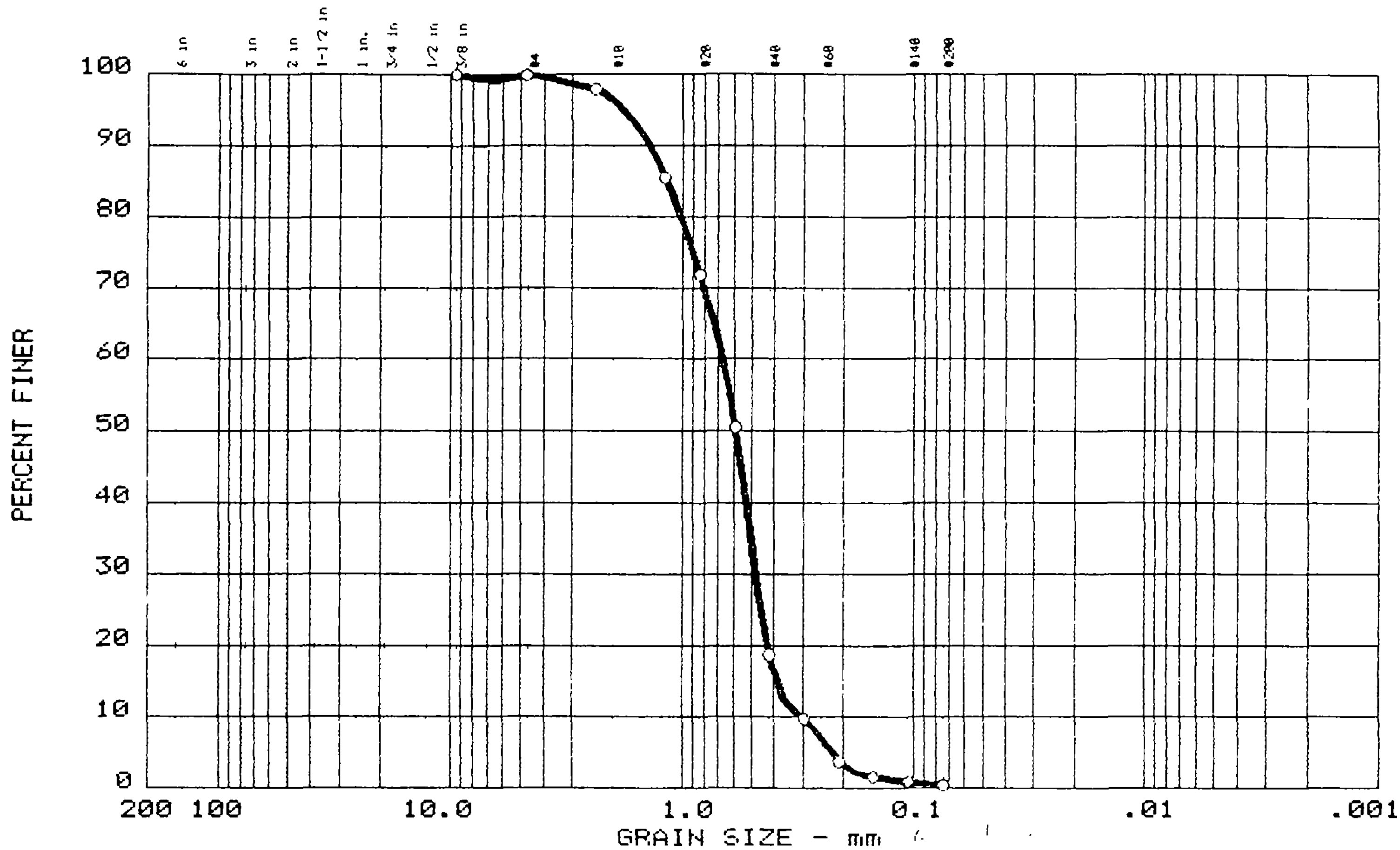
Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.1	99.5	0.4

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.17	0.67	0.59	0.480	0.3904	0.2996	1.15	2.2

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-6H

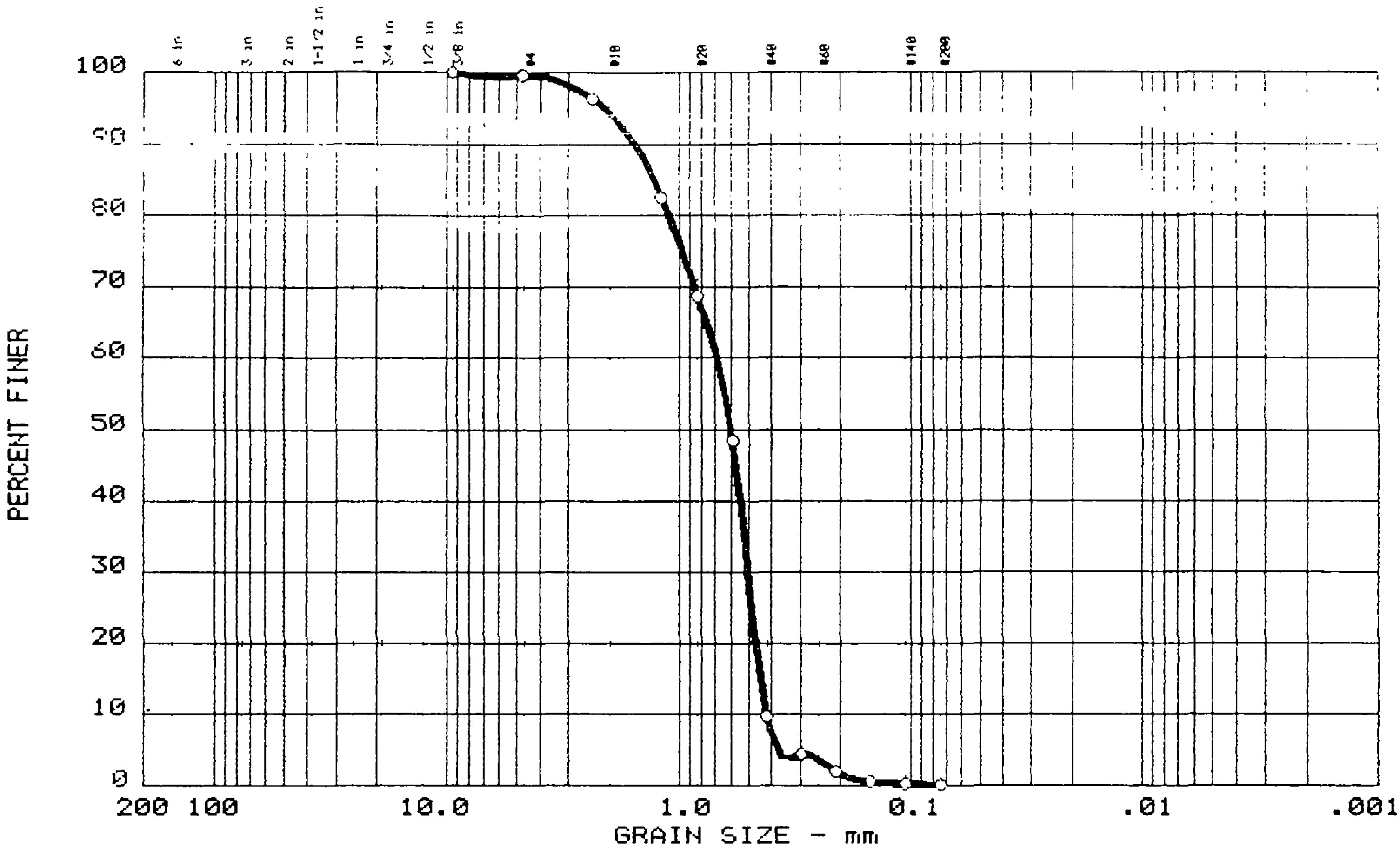
Date: 04-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.4	99.5	0.1

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.28	0.69	0.60	0.506	0.4457	0.4207	0.89	1.6

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP W/TR-G	SP	1	

Project: LAKE HARTWELL STUDY

○ Boring No.: BS-6

Date: 09-22-99

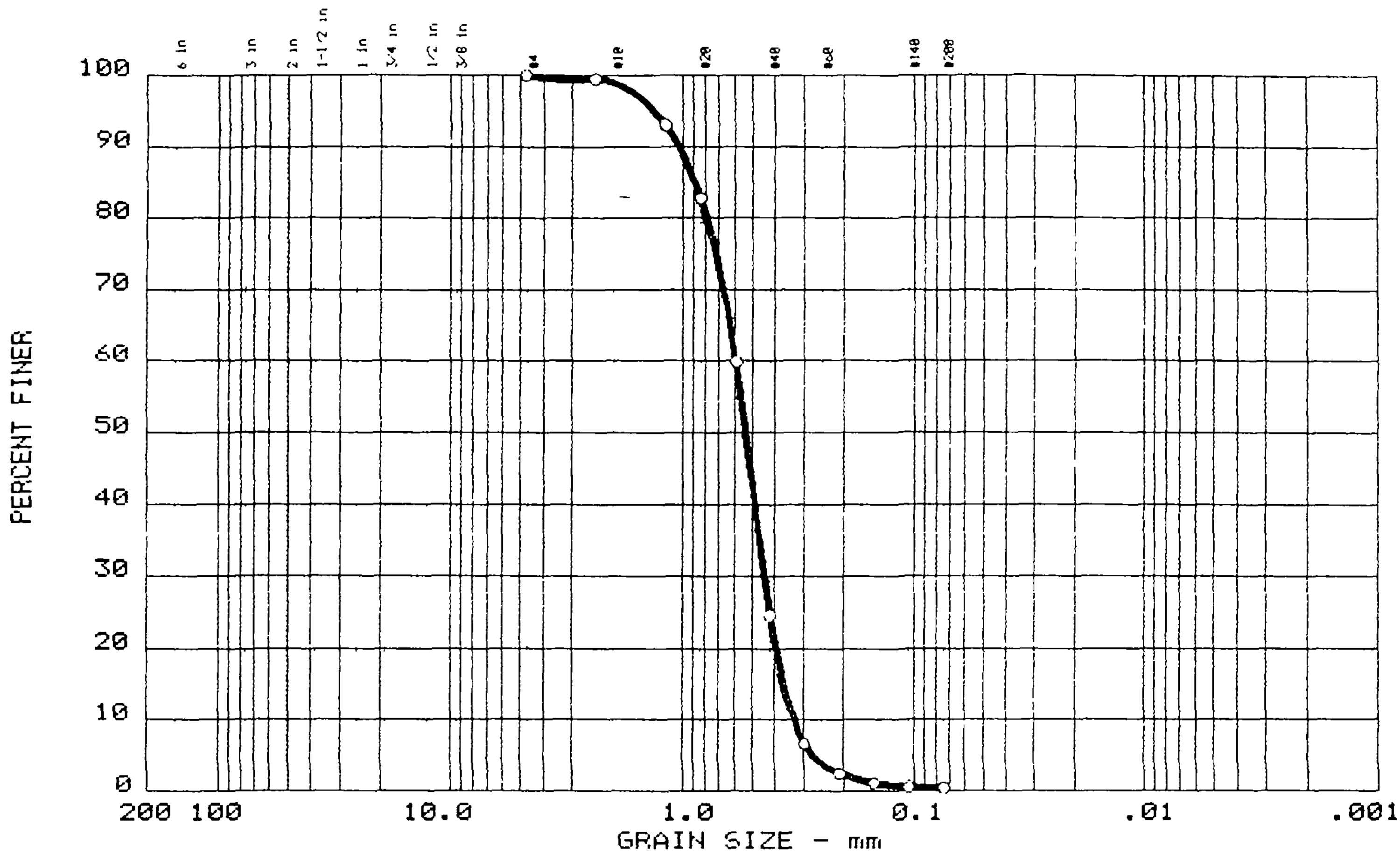
Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. _____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	99.6	0.4

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.89	0.59	0.54	0.445	0.3669	0.3304	1.02	1.8

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-6B

Date: 09-22-99

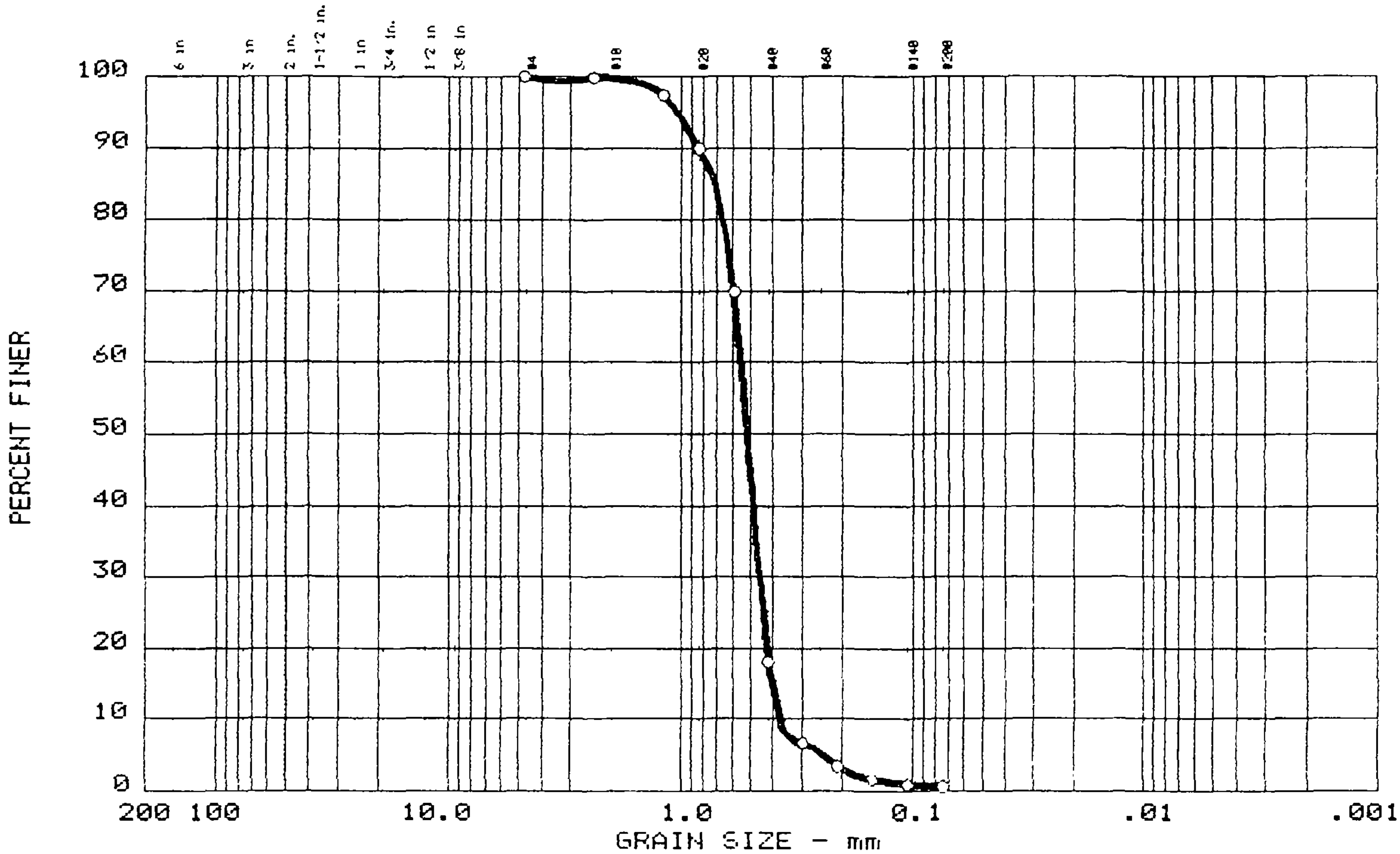
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	99.4	[illegible]

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.71	0.55	0.52	0.459	0.4069	0.3771	1.02	1.5

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-8A

Date: 09-22-99

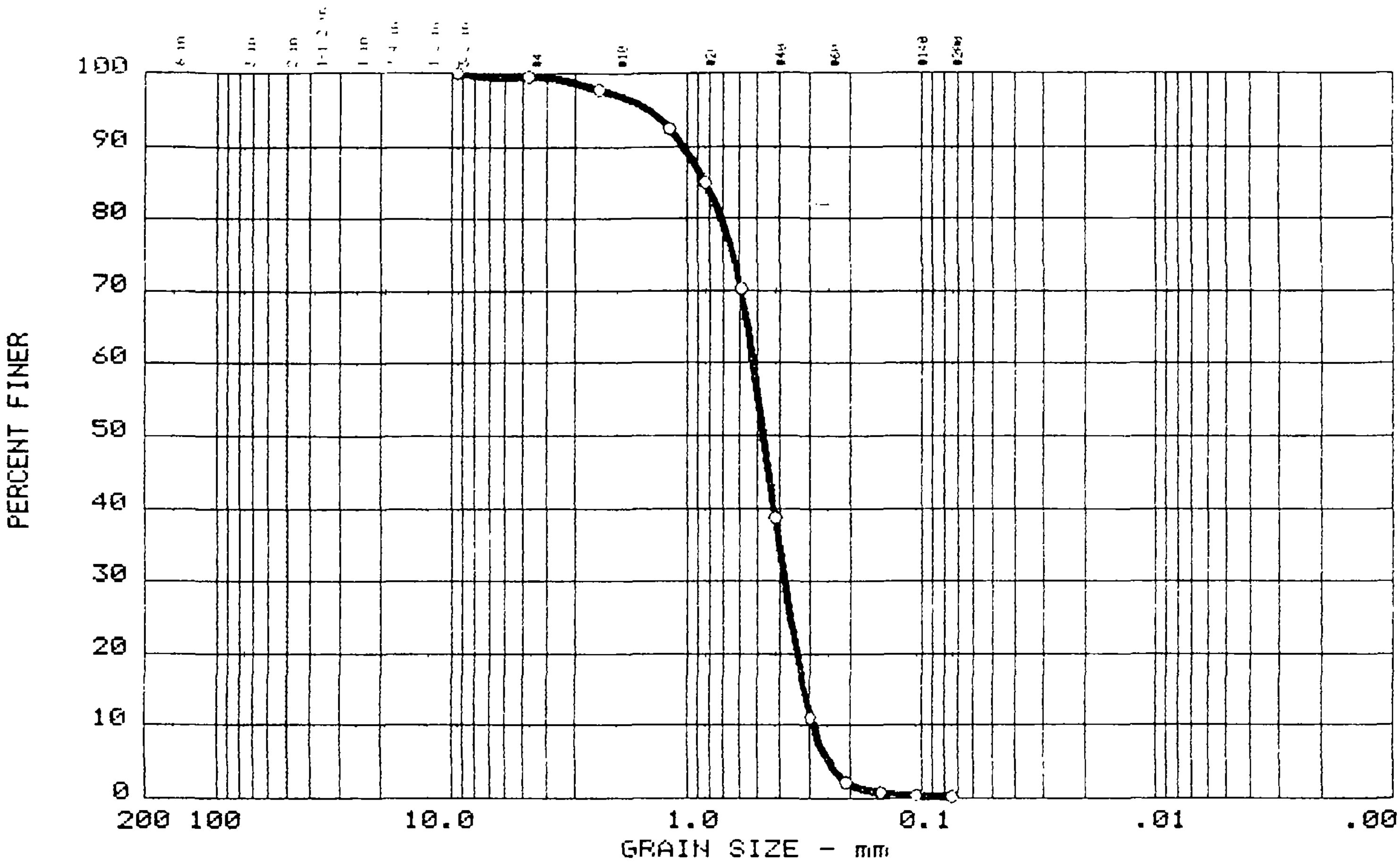
Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.4	99.4	0.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.84	0.52	0.47	0.383	0.3173	0.2904	0.97	1.8

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS 8

Date: 09-22-99

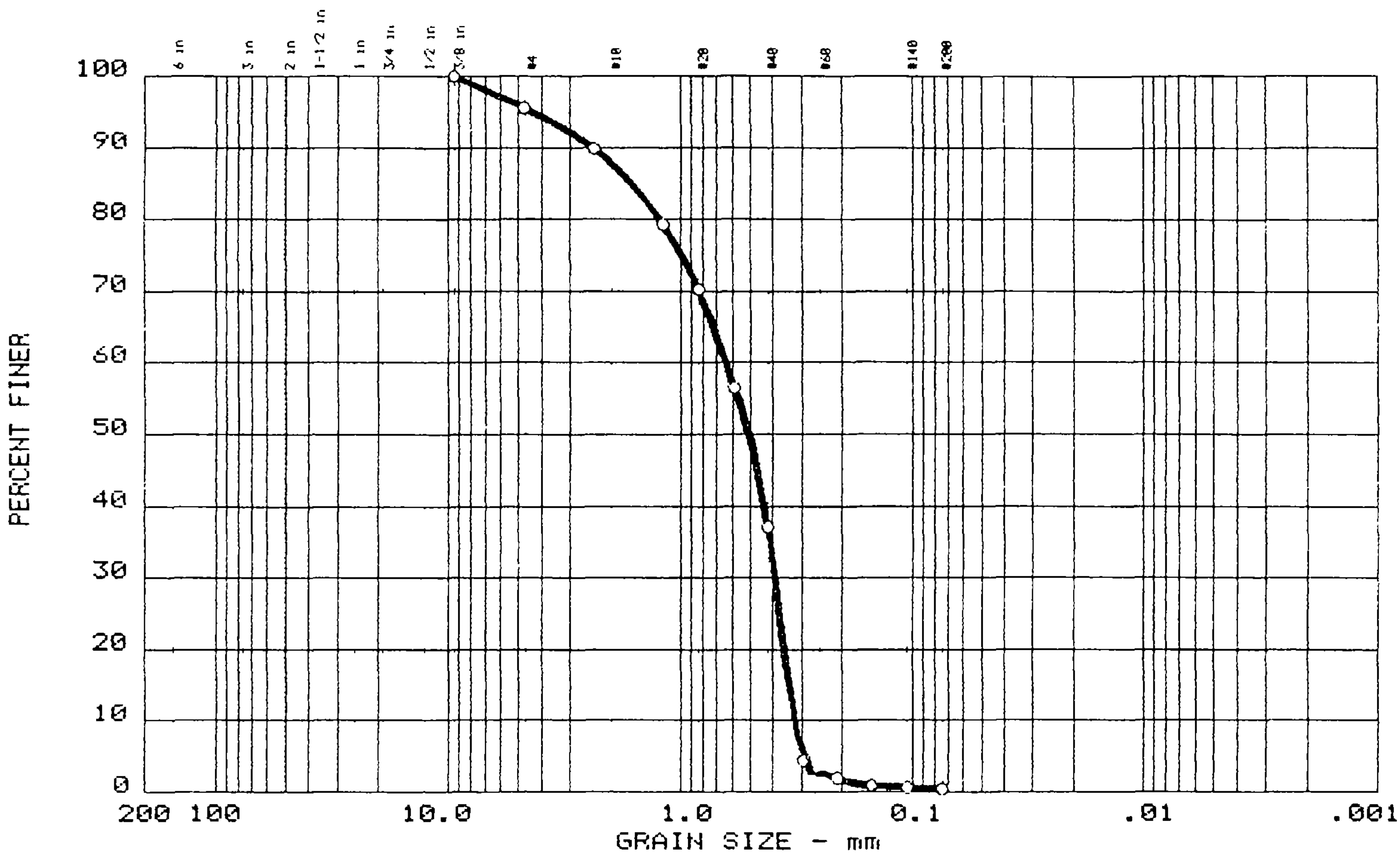
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	4.4	95.3	0.4

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.62	0.64	0.51	0.392	0.3412	0.3236	0.74	2.0

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP W/TR-G	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-8B

Date: 09-22-99

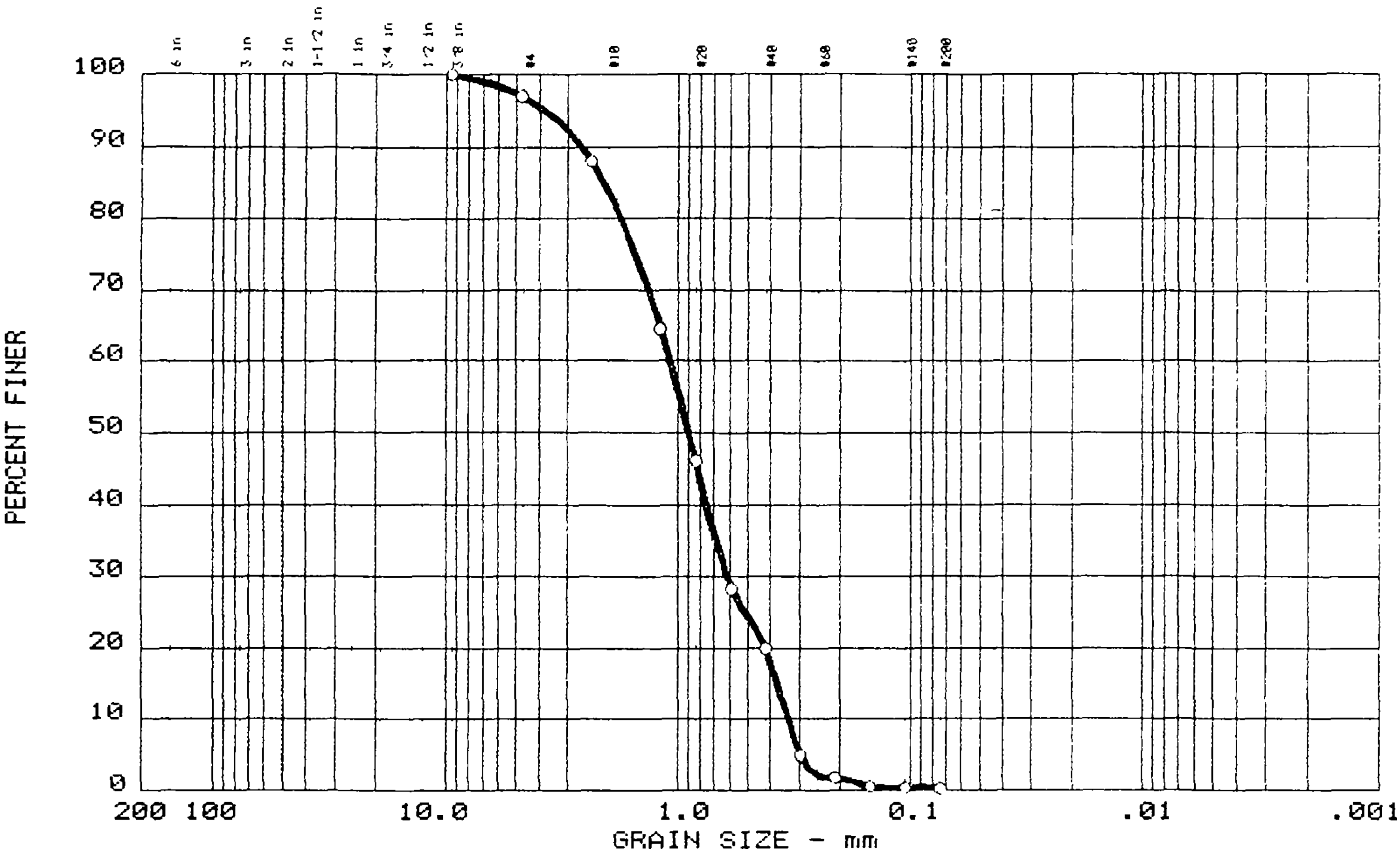
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. _____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	2.9	96.8	0.3

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				2.09	1.08	0.90	0.618	0.3741	0.3373	1.04	3.2

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP W/TR-G	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-9A

Date: 09-22-99

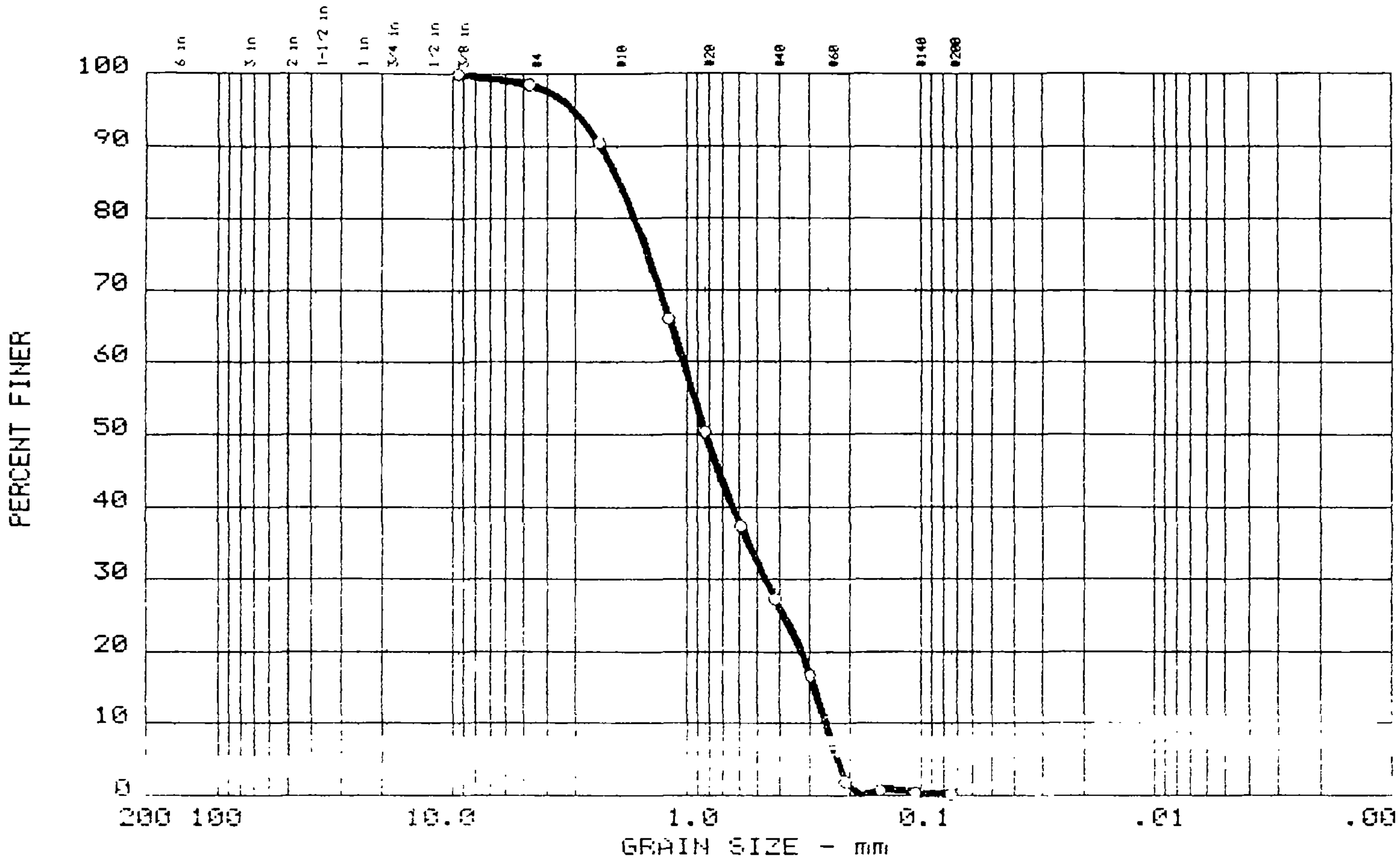
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ______

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	1.4	98.4	0.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.95	1.04	0.83	0.463	0.2854	0.2573	0.80	4.1

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP W/TR-G	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-9

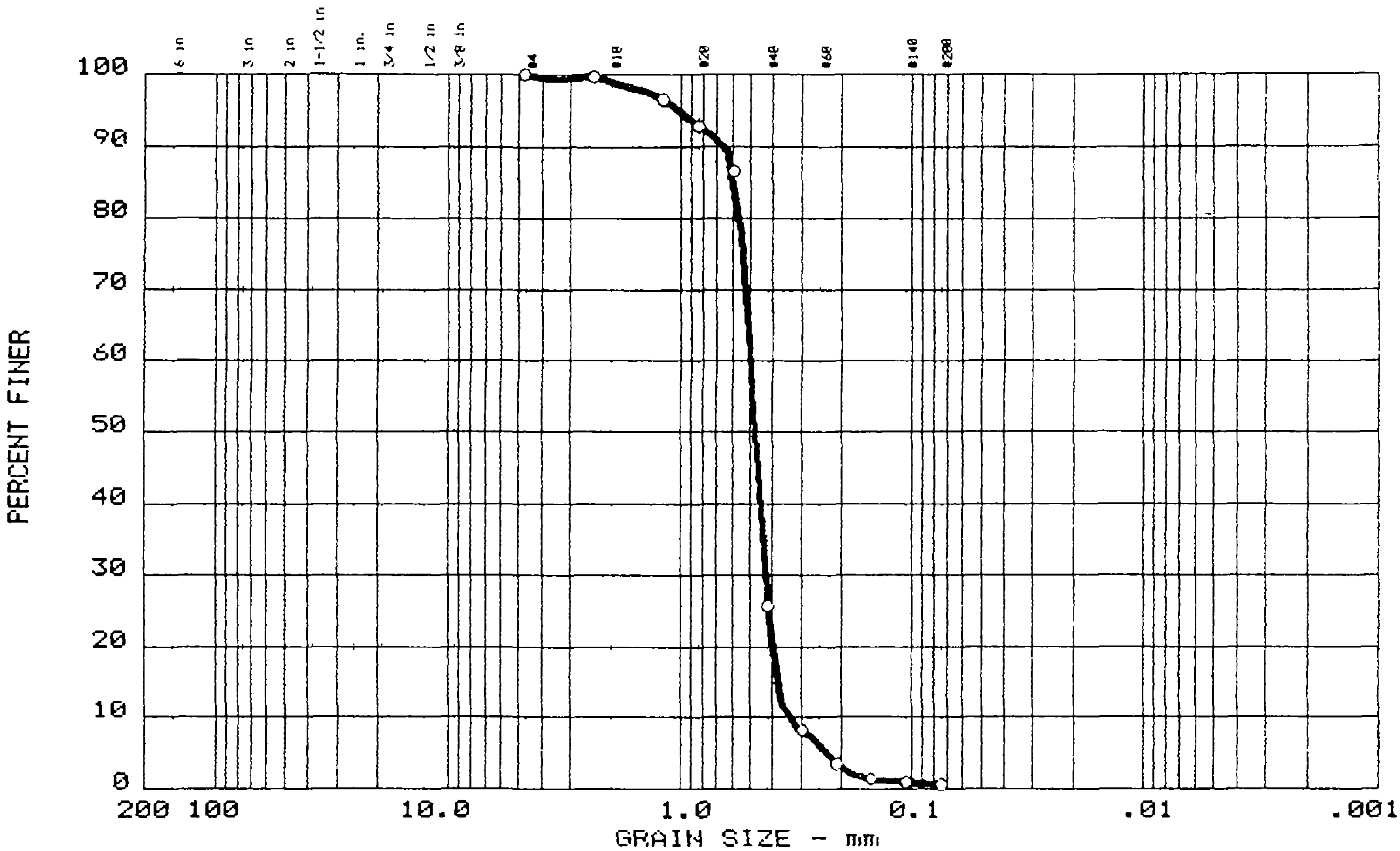
Date: 09-22-99

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	99.4	0.6

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.58	0.50	0.48	0.431	0.3815	0.3439	1.08	1.5

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-9B

Date: 09-22-99

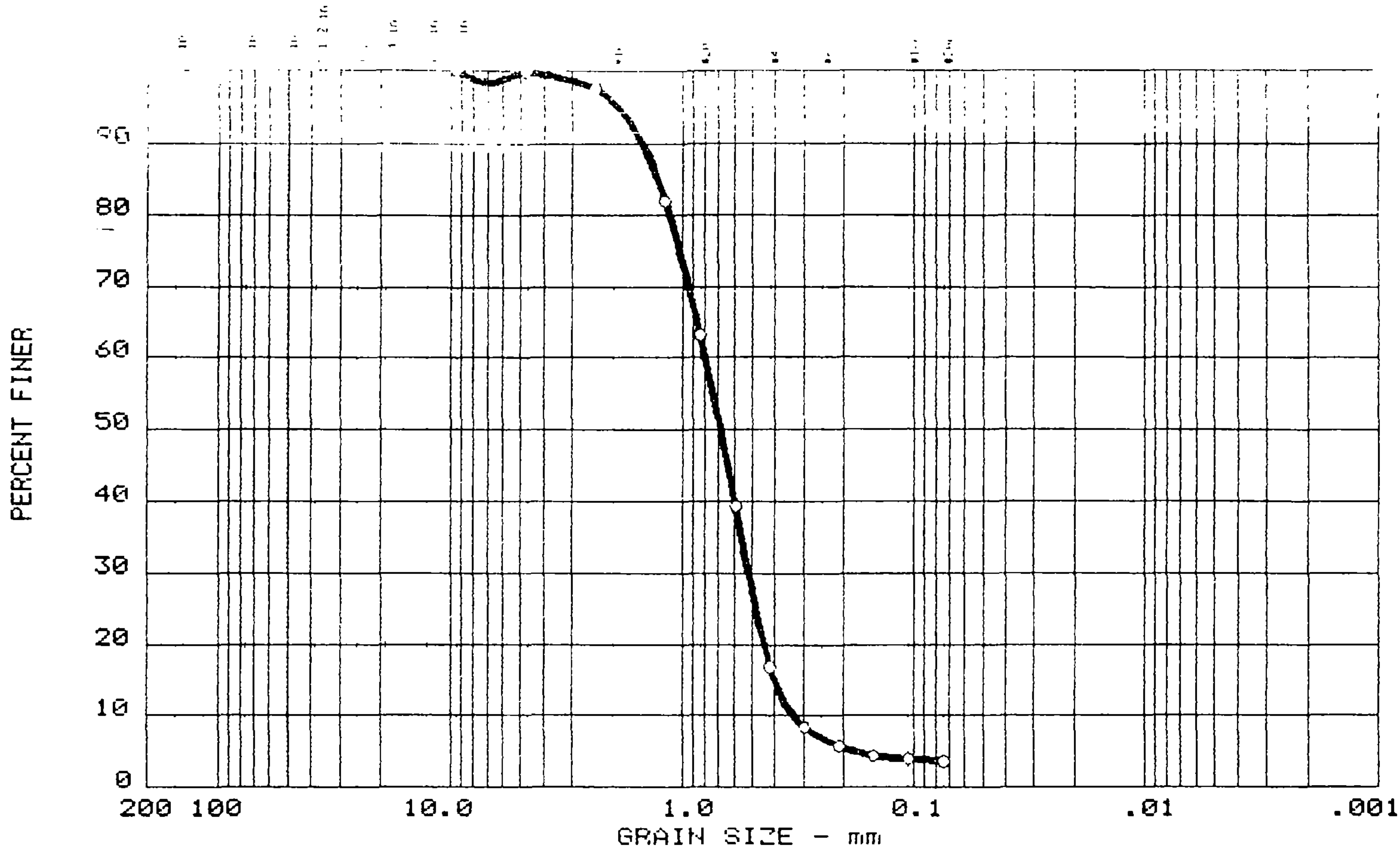
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.2	96.2	3.6

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.28	0.80	0.69	0.519	0.4023	0.3308	1.02	2.4

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-10A

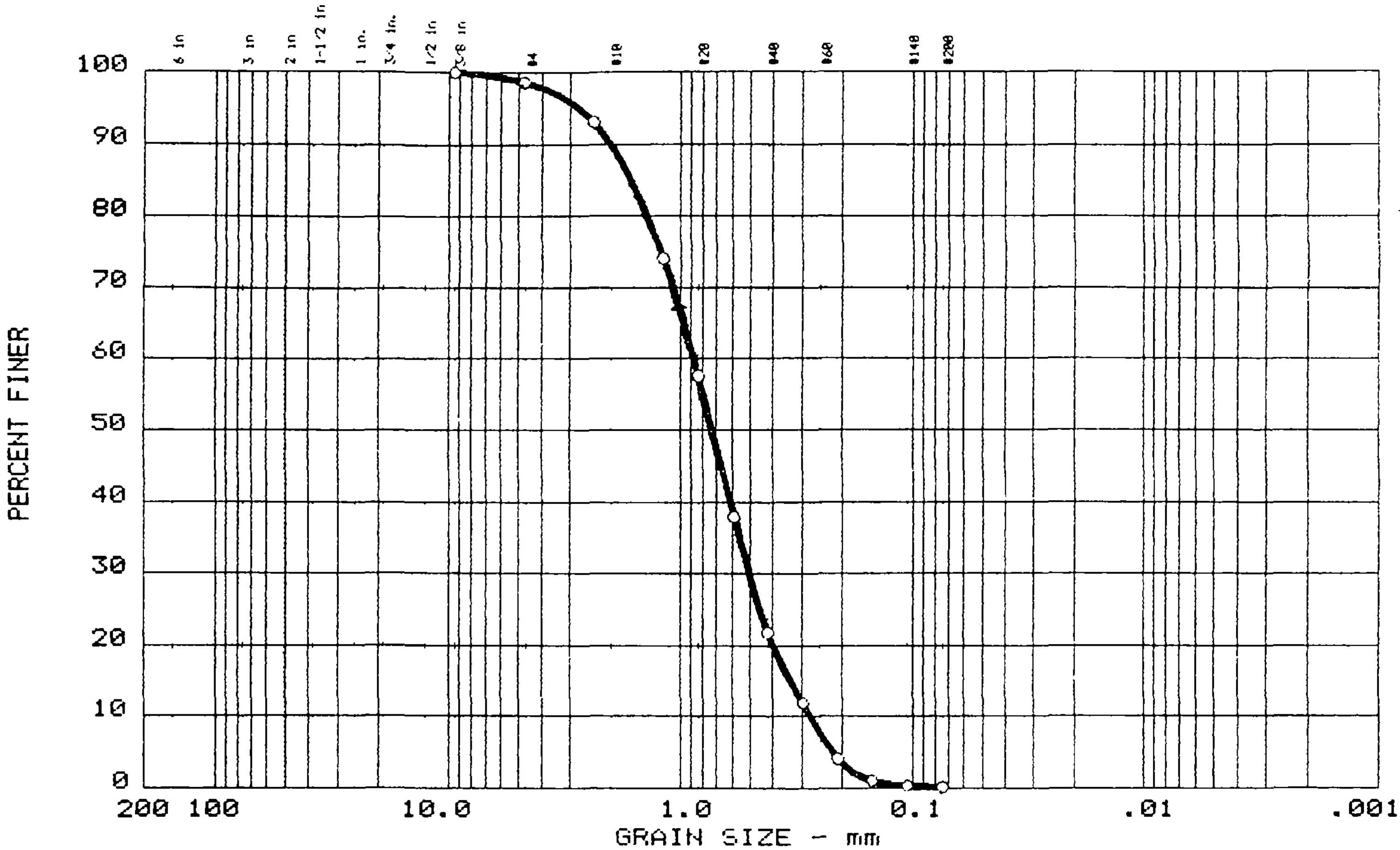
Date: 09-21-99

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	1.4	98.4	0.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.63	0.88	0.73	0.505	0.3365	0.2757	1.05	3.2

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ M-F SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-10

Date: 9-22-99

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Plate No. ____

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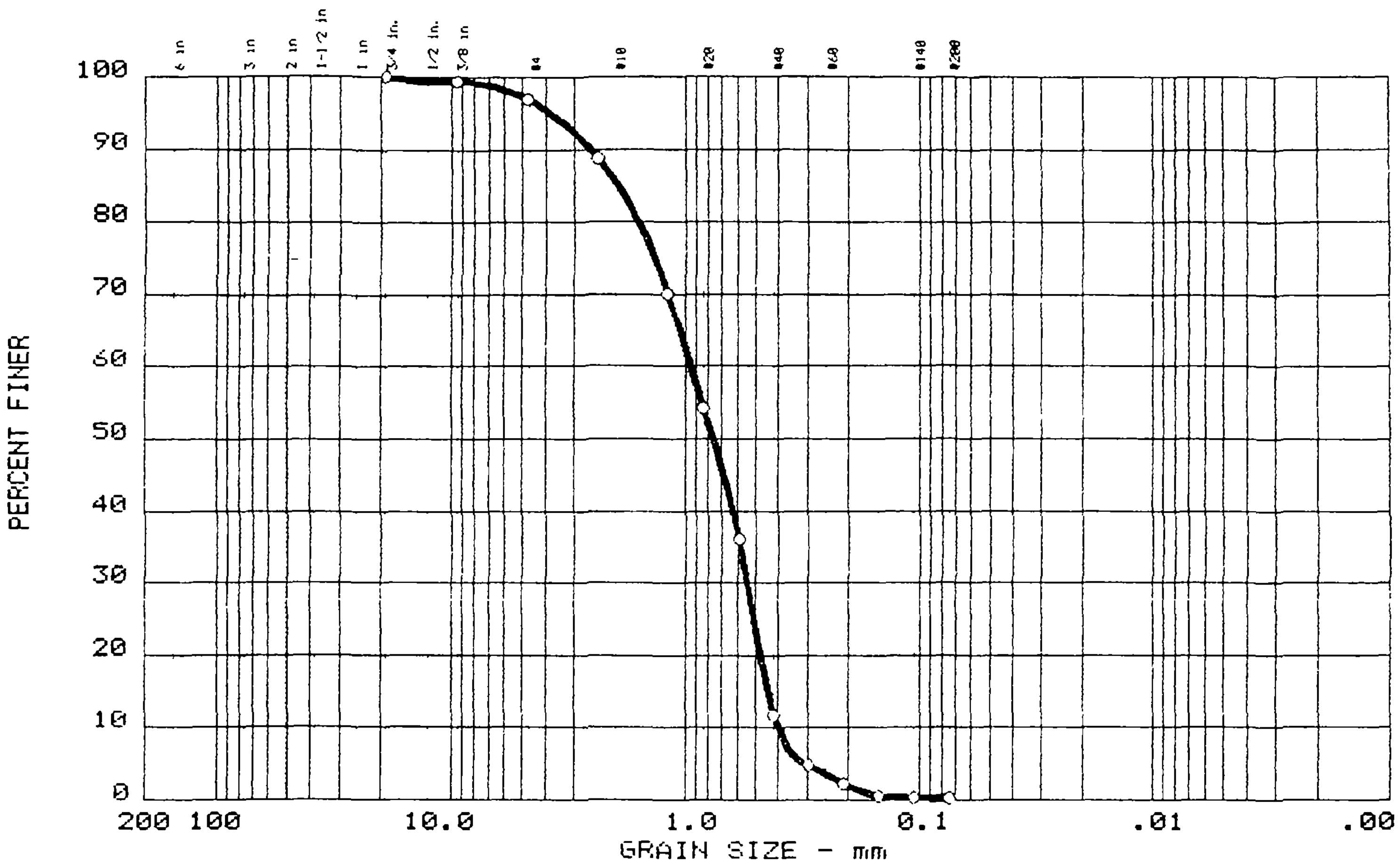

	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	3.0	96.7	0.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.95	0.95	0.76	0.543	0.4441	0.4032	0.77	2.4

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP W/TR-G	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-10-B

Date: 09-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

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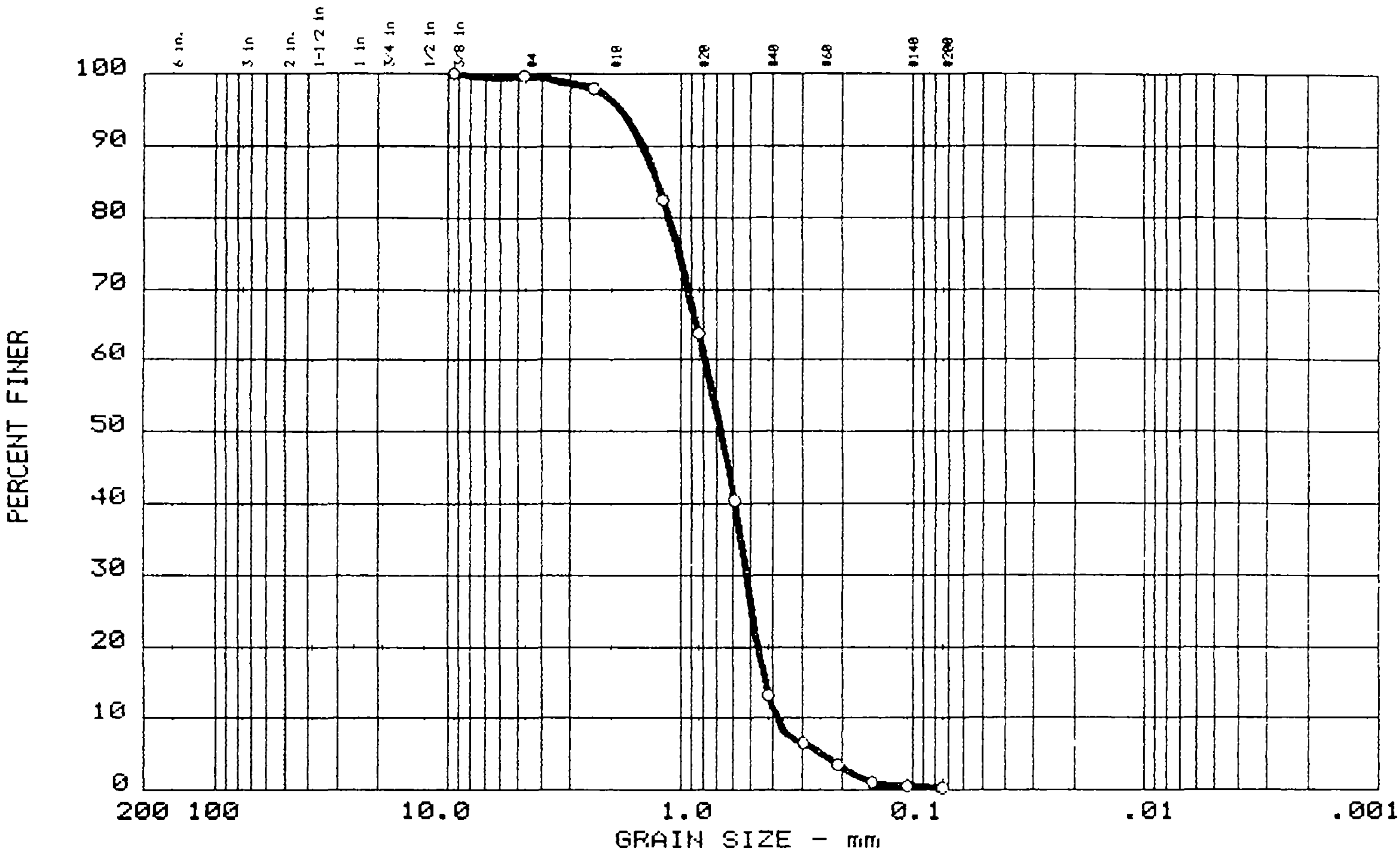

	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.3	99.4	0.3

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.26	0.79	0.67	0.523	0.4330	0.3886	0.90	2.0

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-10A-A

Date: 09-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

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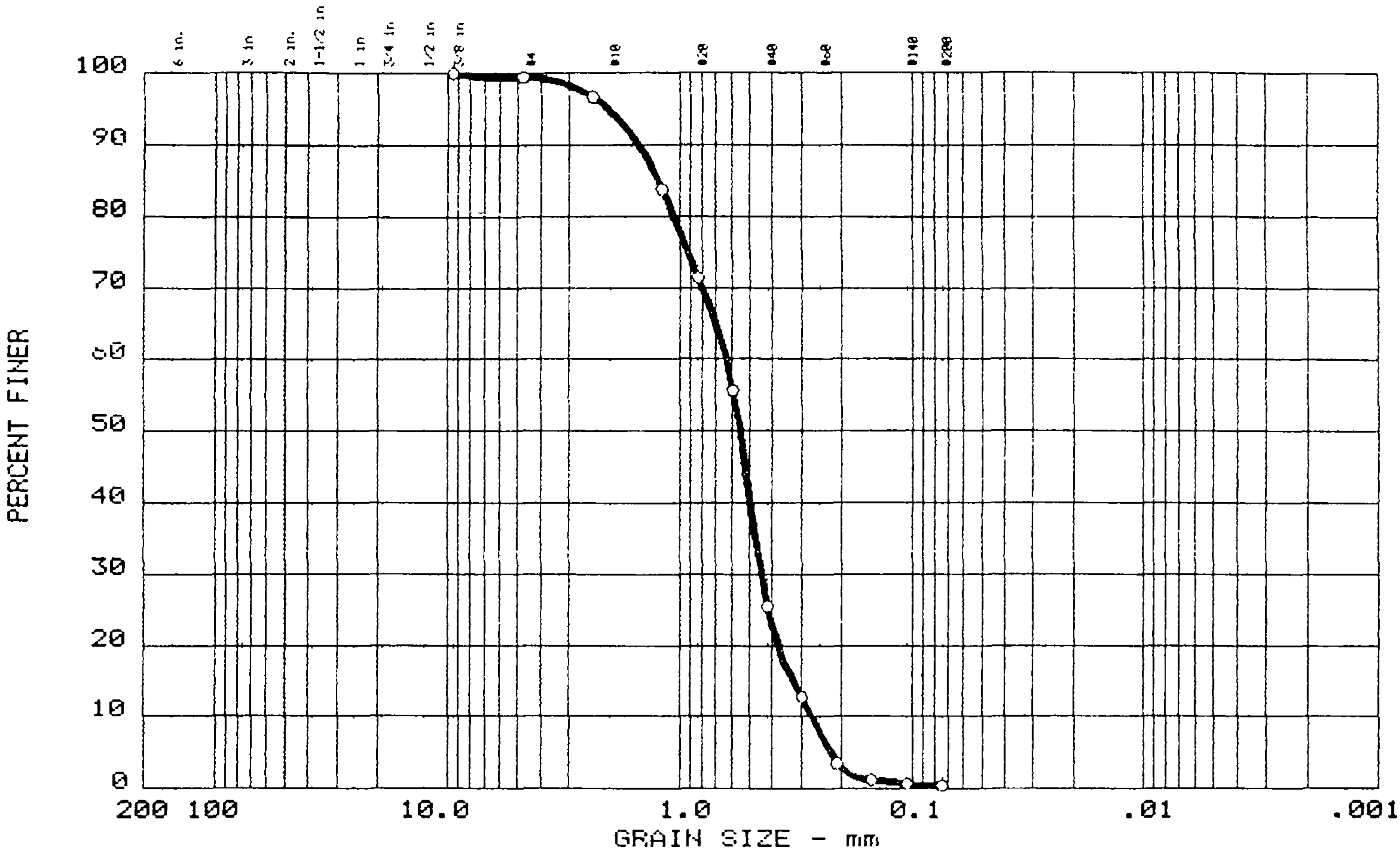

	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.6	99.0	0.4

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.24	0.63	0.55	0.445	0.3255	0.2676	1.17	2.4

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-10-A

Date: 09-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

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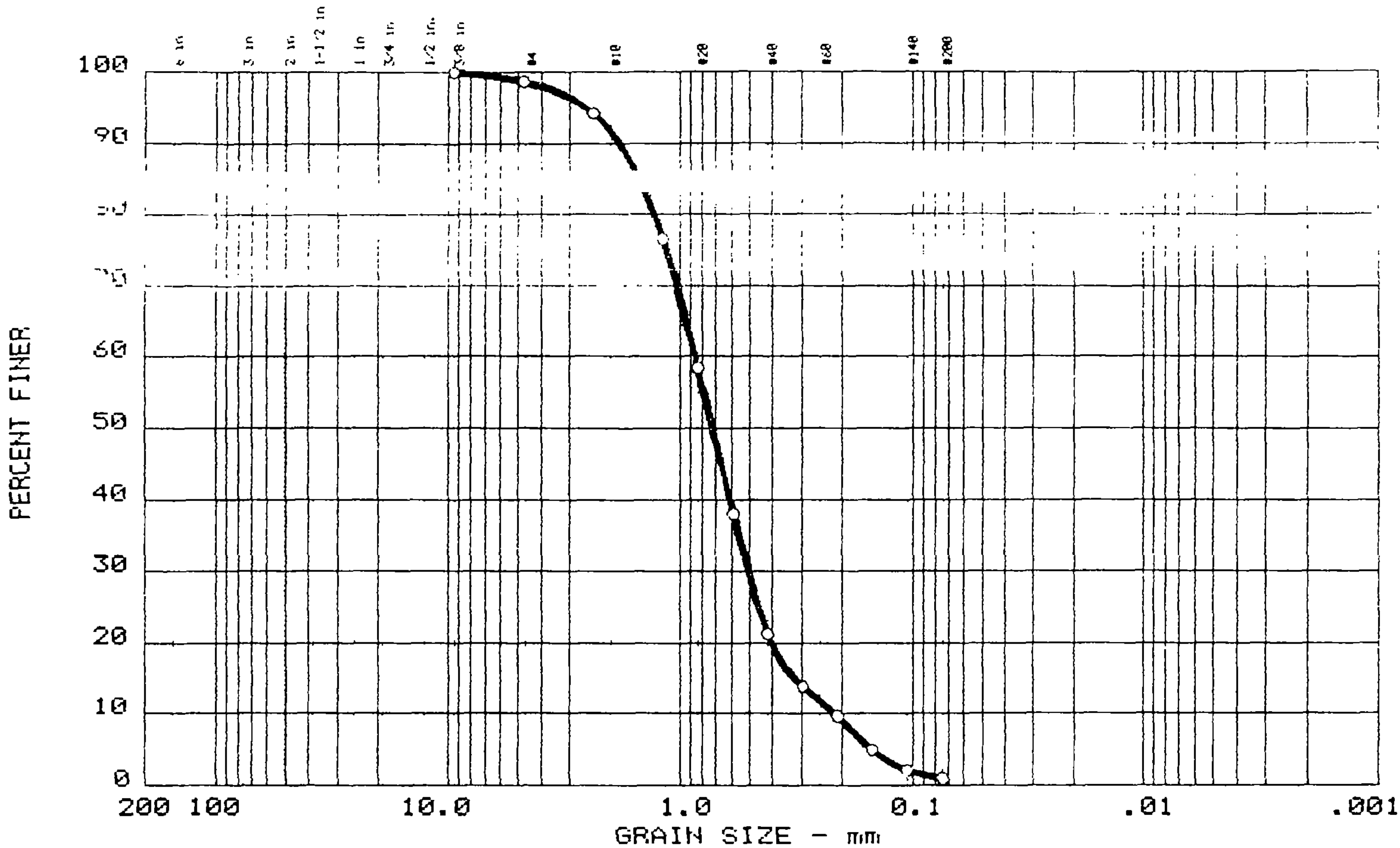

	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	1.3	97.7	1.0

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.50	0.86	0.72	0.510	0.3217	0.2150	1.40	4.0

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP W/TR-G	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-10-AB

Date: 09-22-99

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

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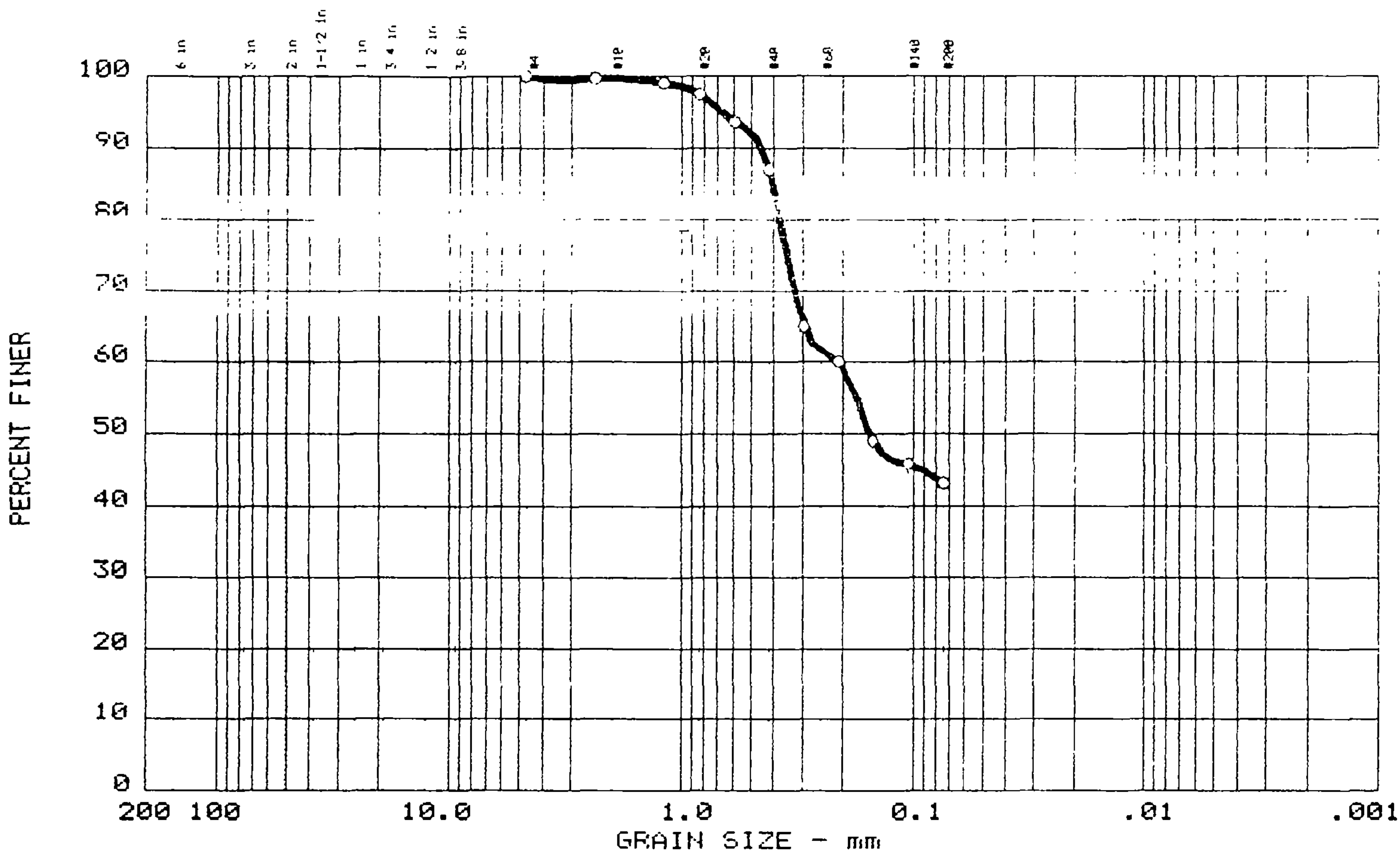

	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	56.8	43.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.40	0.21	0.15					

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ SILT SAND SM	SM	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-11-A

Date: 09-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

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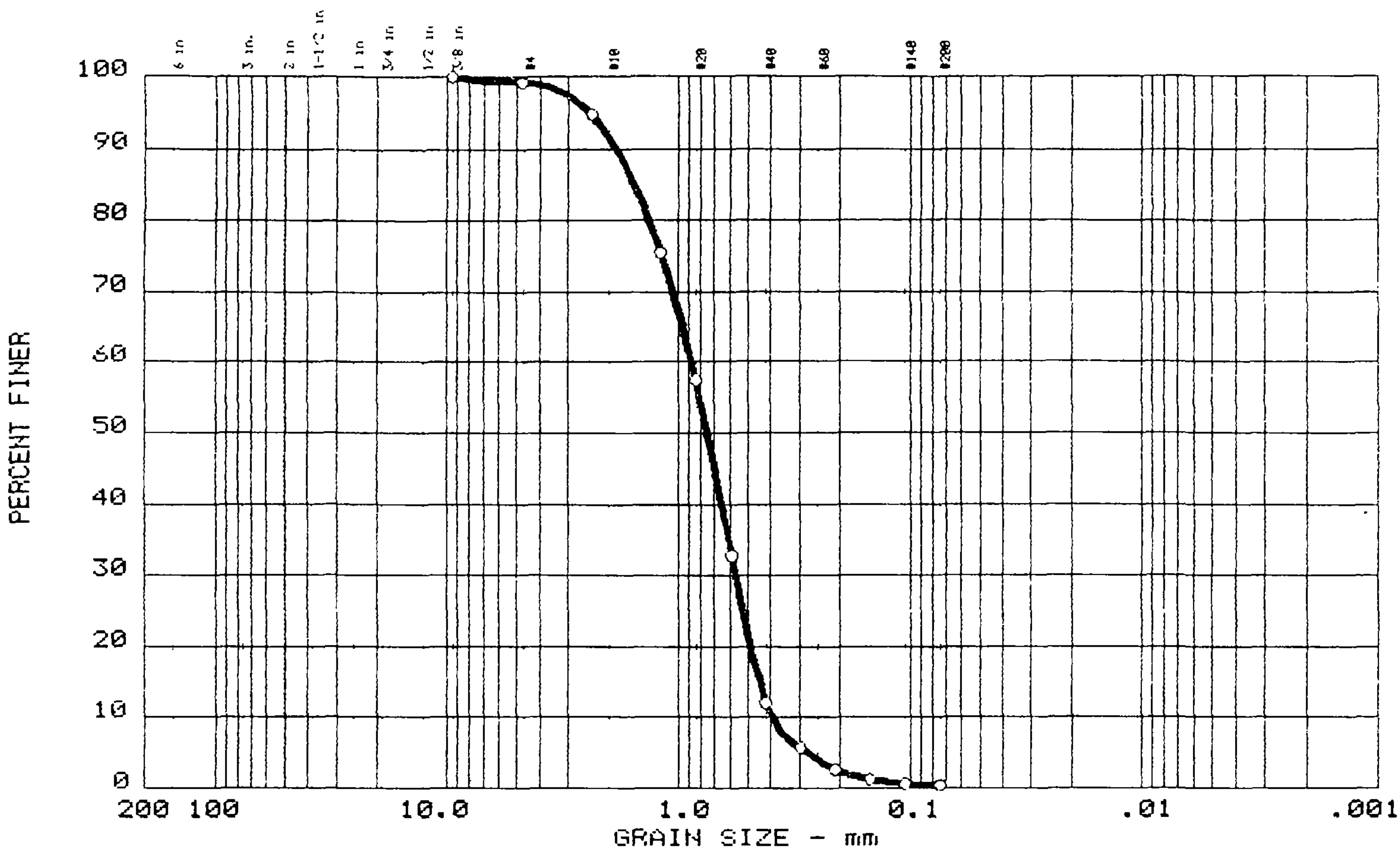

	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.7	98.8	0.4

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.55	0.87	0.75	0.568	0.4482	0.3949	0.93	2.2

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-11

Date: 09-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

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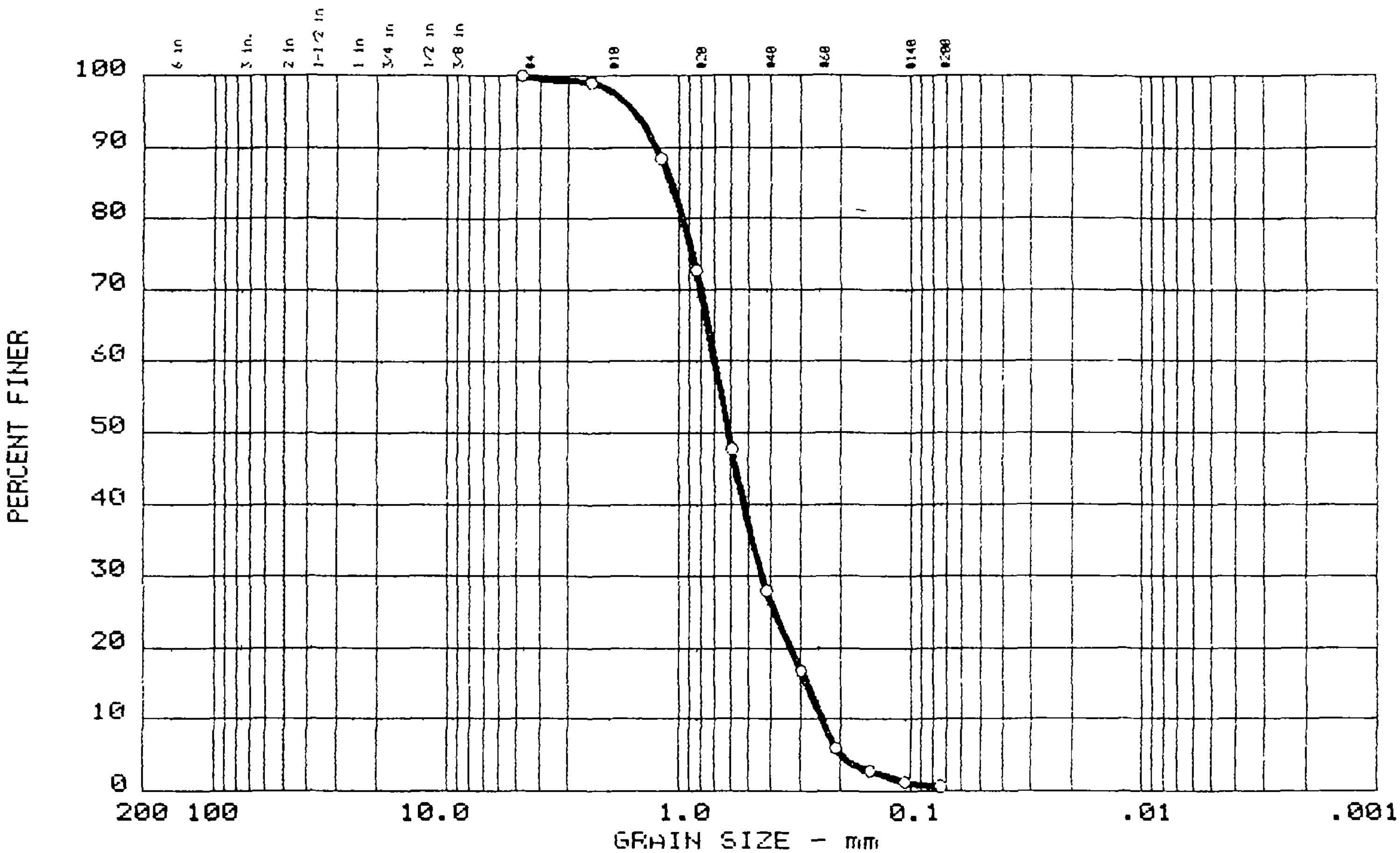
GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	99.4	0.6

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.08	0.70	0.61	0.440	0.2805	0.2415	1.15	2.9

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-11B

Date: 09-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

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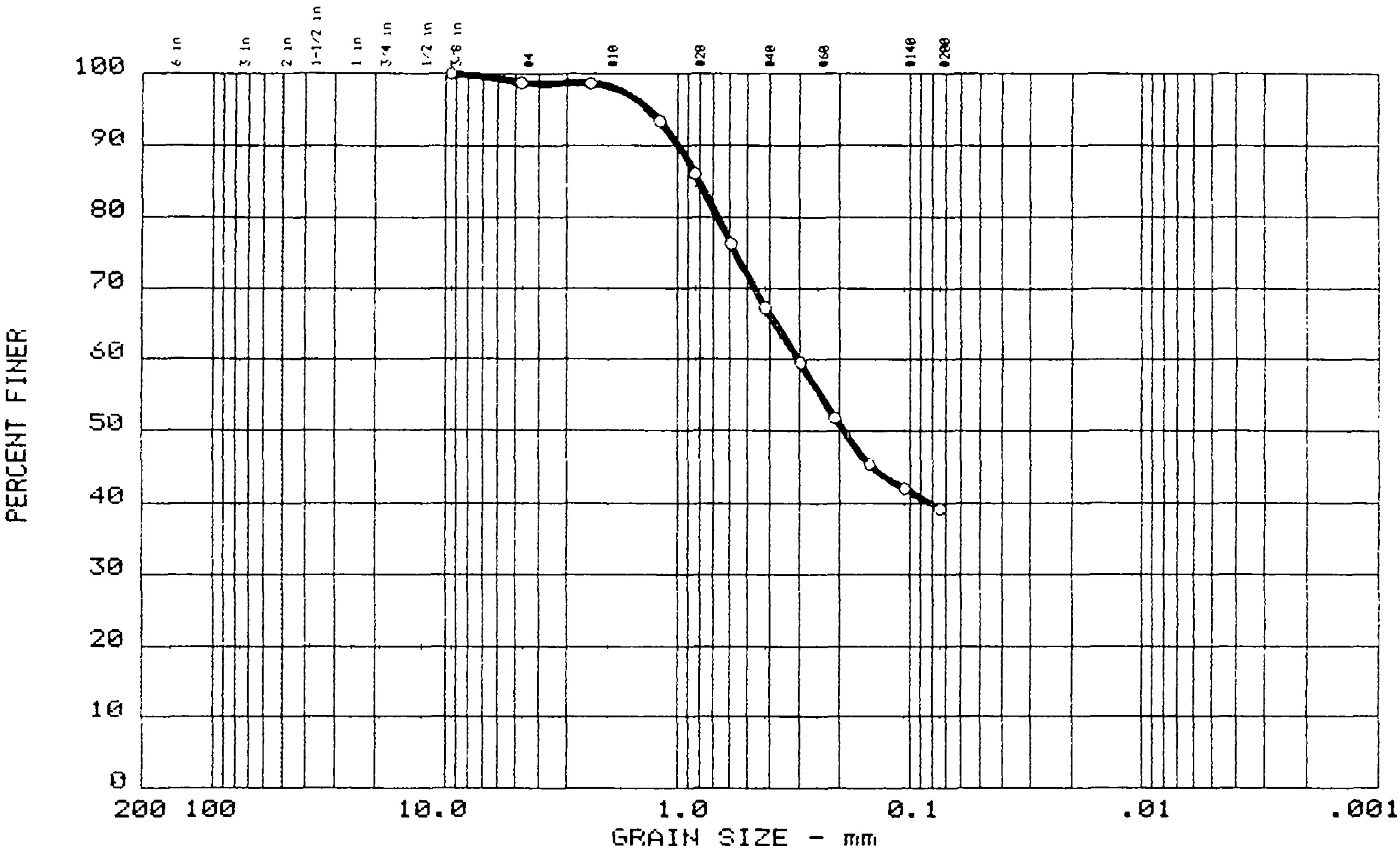
GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	1.2	59.6	39.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.80	0.30	0.19					

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ SILTY SAND SM	SM	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-12-A

Date: 09-21-99

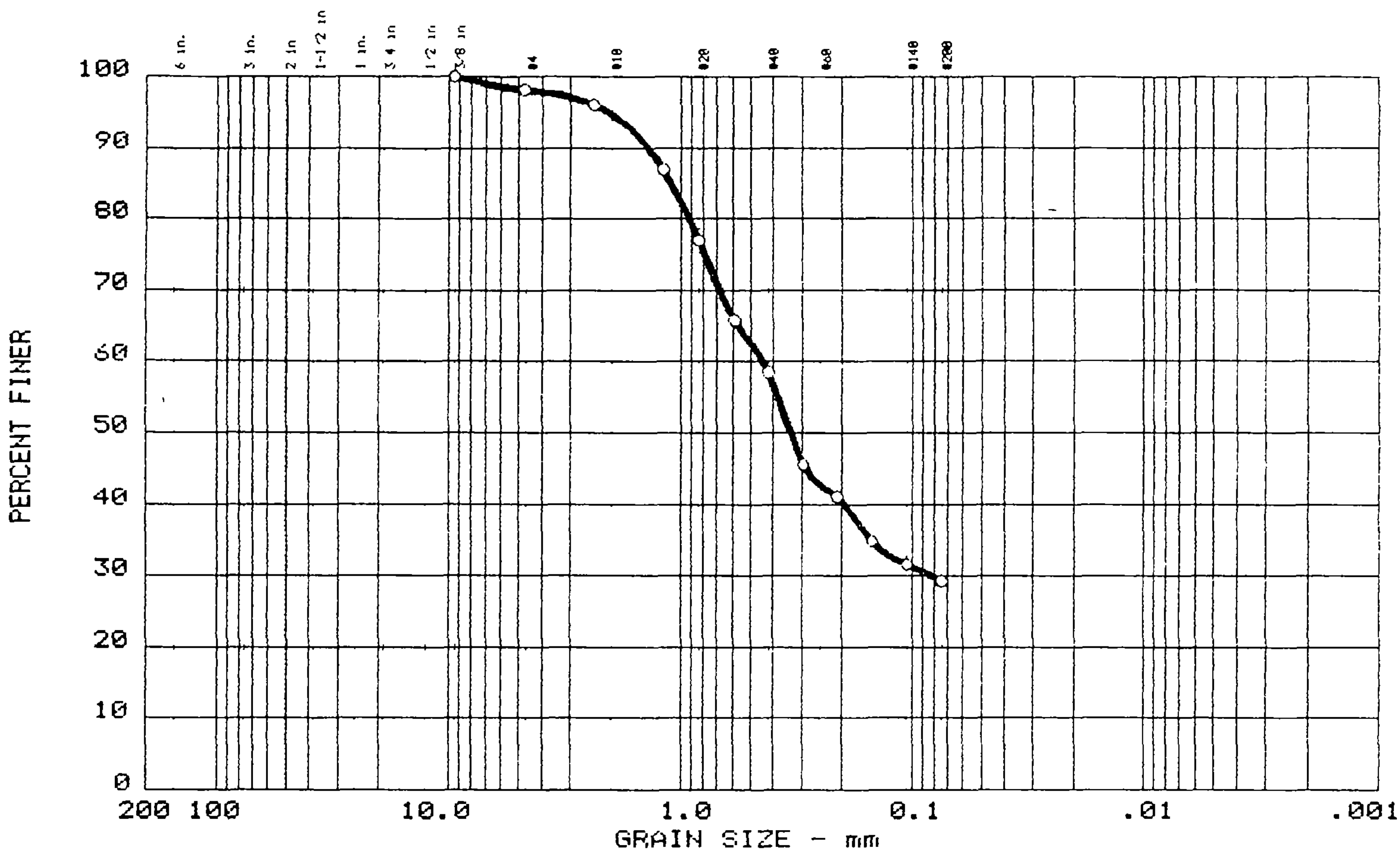
GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	1.8	68.9	29.3

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.10	0.44	0.34	0.082				

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ SILTY SAND SM	SM	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-12-B

Date: 09-21-99

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

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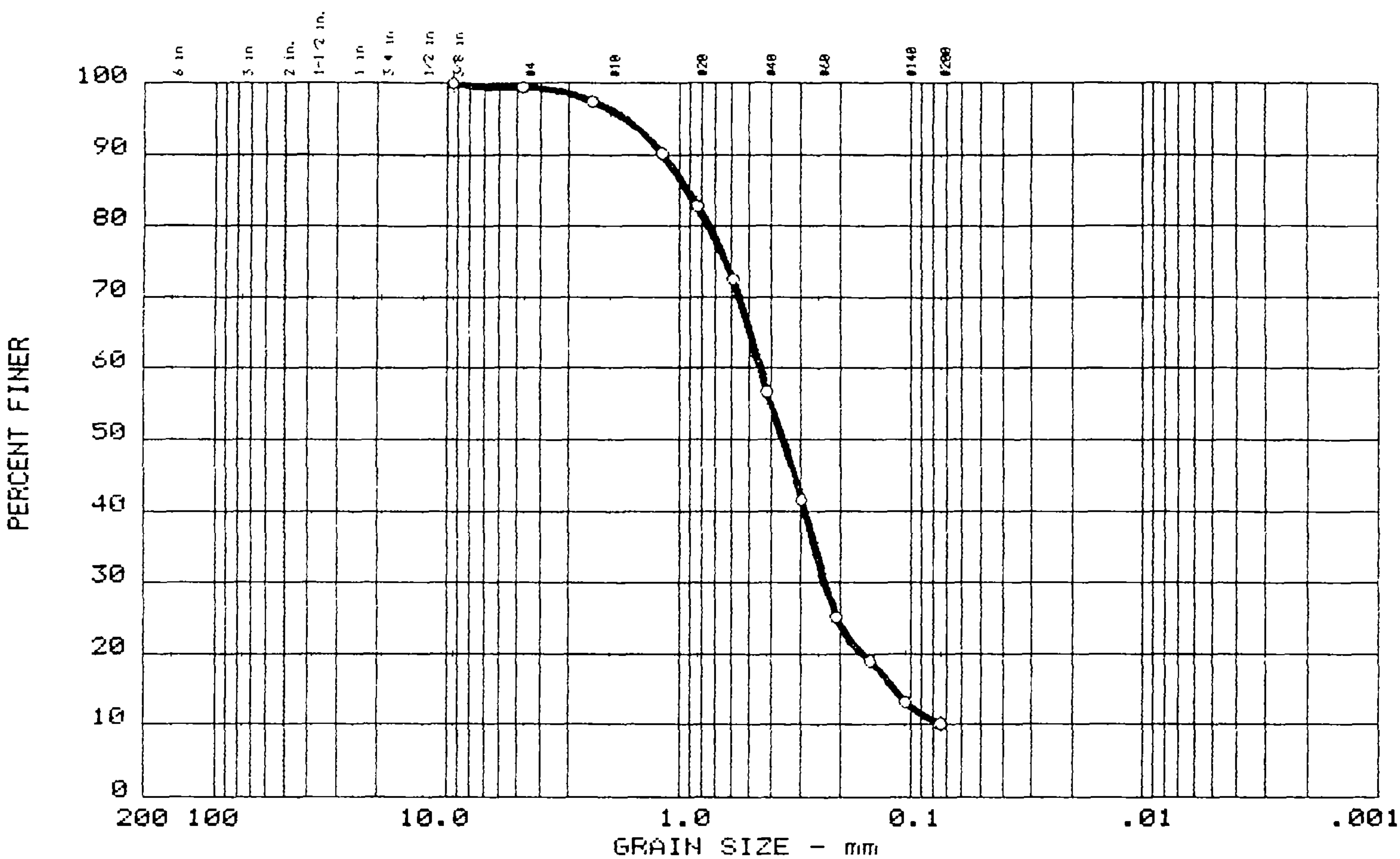
GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.6	89.2	10.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.92	0.45	0.36	0.236	0.1171			

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ SP-SM	SP-SM	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-13-A

Date: 9-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

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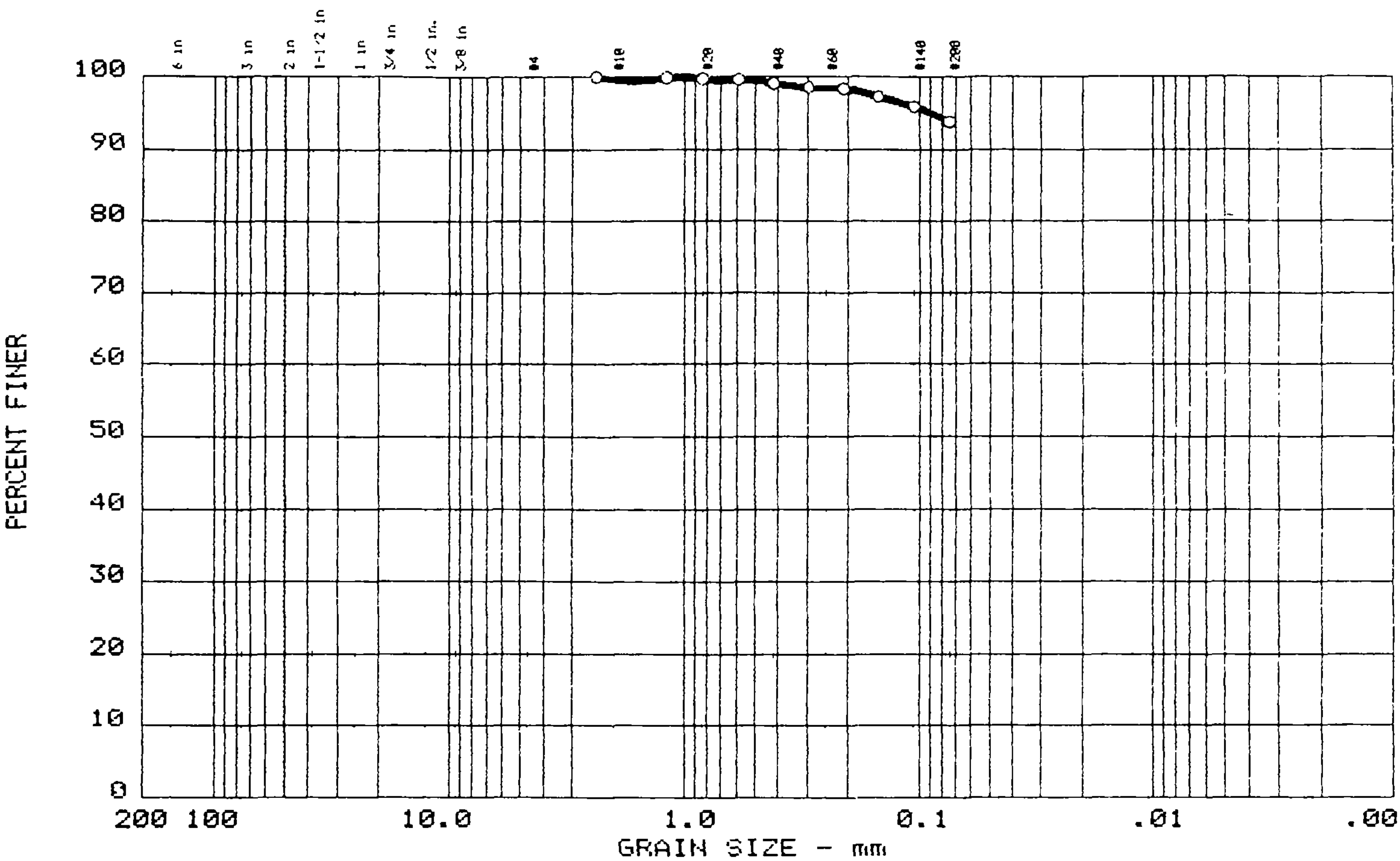
GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	6.2	93.8

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○											

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ SILT ML	ML	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-13

Date: 9-22-99

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
CORPS OF ENGINEERS - VICKSBURG DISTRICT

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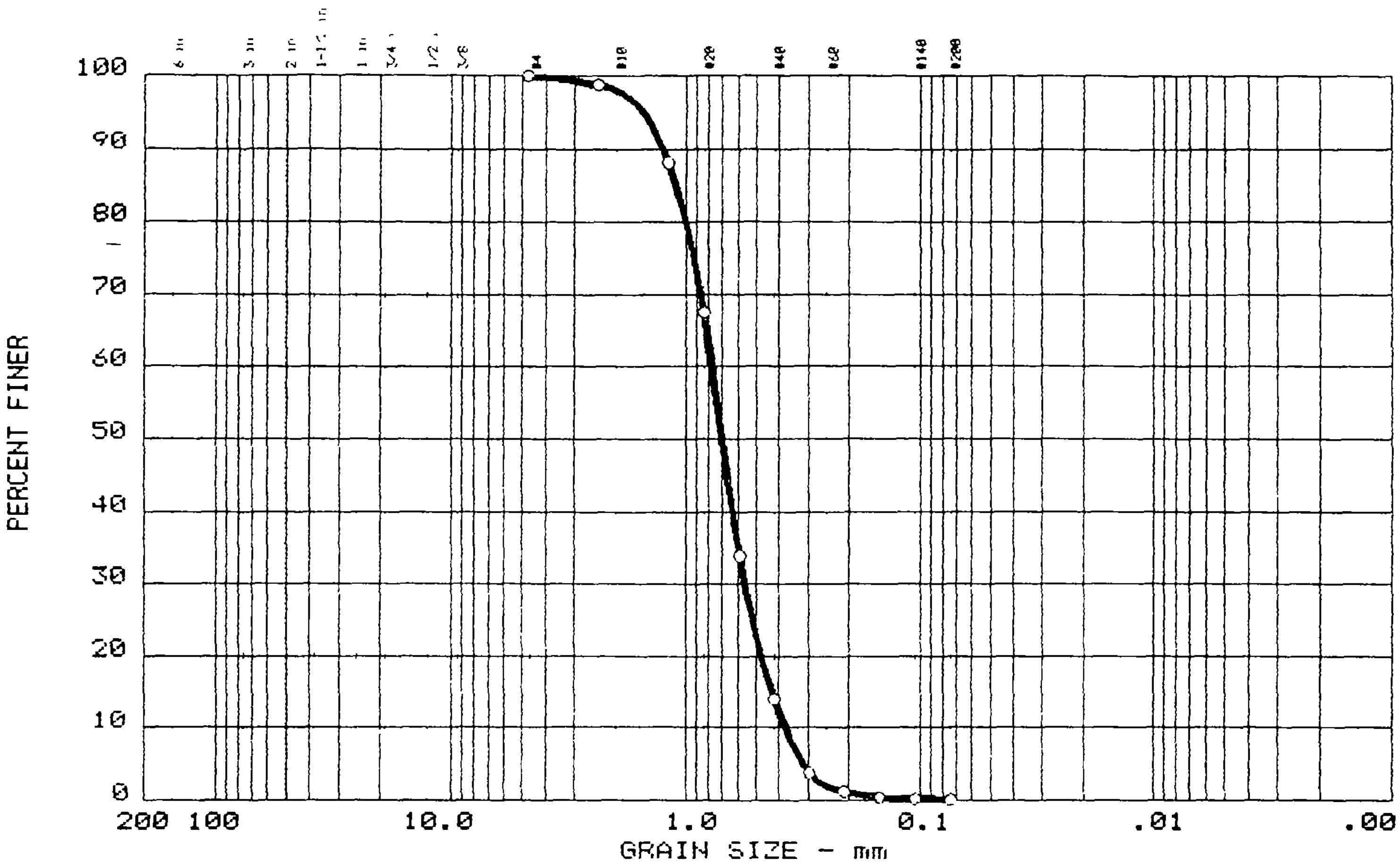

	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	99.8	0.2

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				1.10	0.77	0.70	0.562	0.4295	0.3771	1.08	2.1

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ M-F SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-13-B

Date: 9-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

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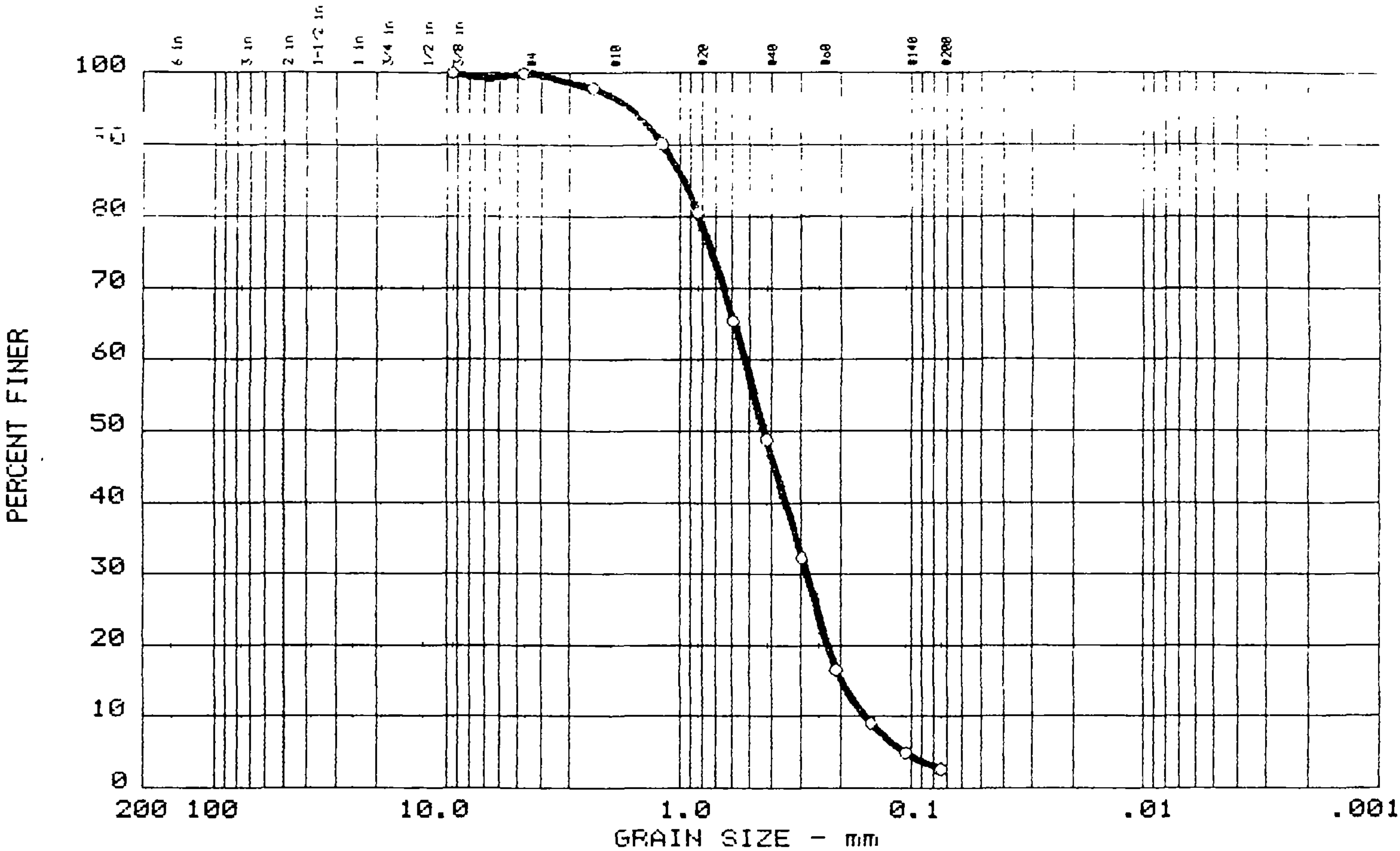

	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.1	97.2	2.7

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.96	0.53	0.43	0.283	0.2000	0.1570	0.97	3.4

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ F-M SAND SP	SP	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-14-A

Date: 9-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

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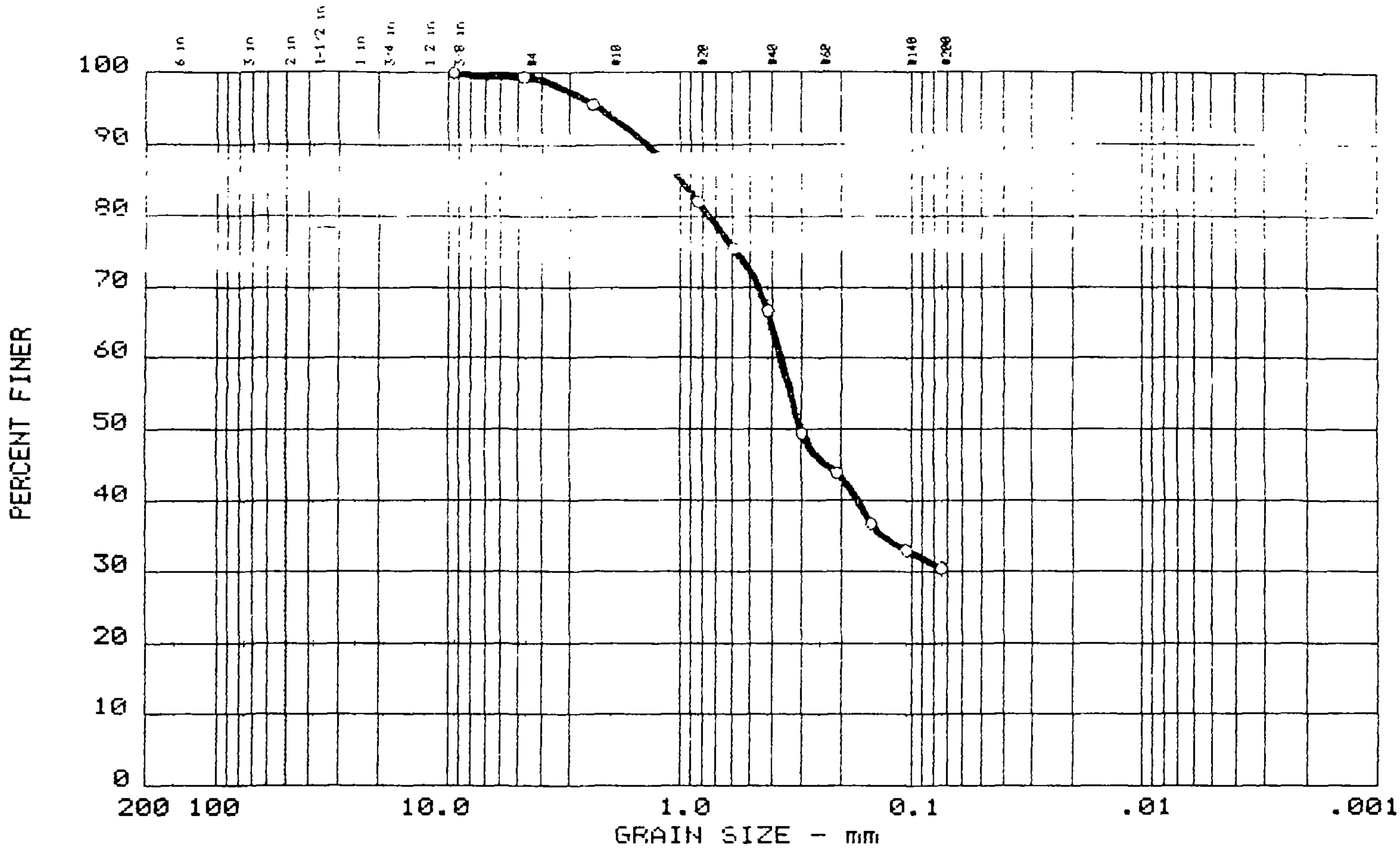
GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.7	68.9	30.4

	LL	PL	NWC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.99	0.37	0.30					

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ SILTY SAND SM	SM	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-14

Date: 09-21-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

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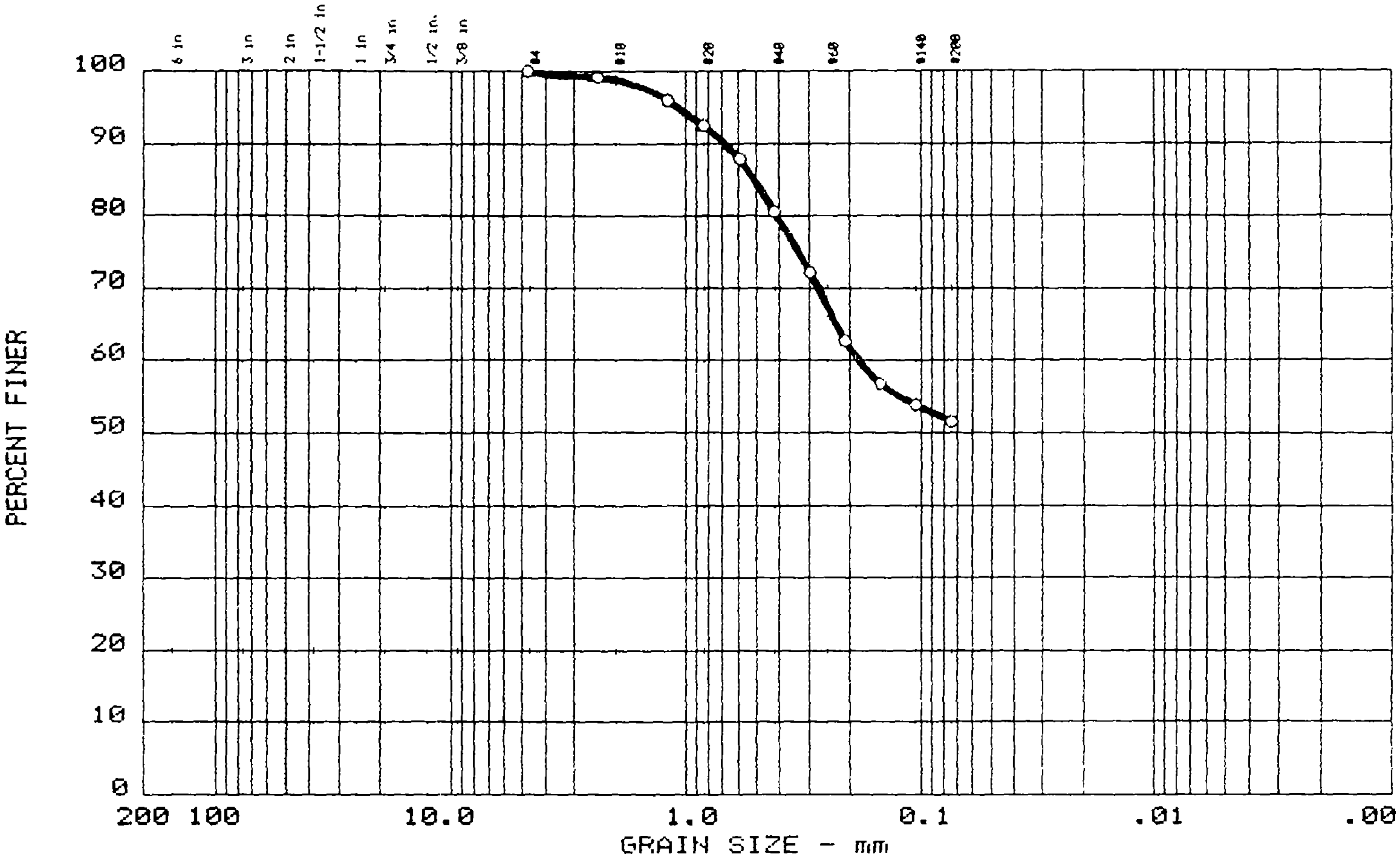
GRAIN SIZE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% FINES
○	0.0	0.0	48.4	51.6

	LL	PL	NMC	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
○				0.51	0.18						

MATERIAL DESCRIPTION	USCS	Sam #	Depth
○ SILT ML	ML	1	

Project: LAKE HARTWELL STUDY
○ Boring No.: BS-14-B

Date: 9-22-99

GRAIN SIZE DISTRIBUTION TEST REPORT

CORPS OF ENGINEERS - VICKSBURG DISTRICT

Remarks:

Plate No. ____

APPENDIX E

Summary of Previous HEC-6 Modeling Efforts by Bechtel

Appendix F

HEC-6 Sediment Transport Model

REF: MAY 1993 REMEDIAL INVESTIGATION REPORT

L384

Appendix F
Twelvemile Creek/Hartwell Lake Sediment Transport Modeling (HEC-6) Report

1.0 INTRODUCTION

In 1991, Bechtel Environmental, Inc. (Bechtel) conducted a field investigation study in the Twelvemile Creek/Hartwell Lake area of South Carolina (Bechtel 1992) as part of the remedial investigation/feasibility study for the PCB-contaminated Sangamo Superfund Site. Results of the field study indicated that PCBs at above-background levels were detected in most of the sampling locations in the lower reach of Twelvemile Creek. A water-quality modeling study was therefore proposed to investigate the potential migration of PCBs and to estimate future PCB distributions in the Twelvemile Creek/Hartwell Lake river system.

Published experimental results on the physico-chemical properties of PCBs indicate that PCBs exhibit high affinity for the organic carbon fractions of fine-grained sediments. One of the main transport mechanisms of PCBs in an aquatic system is therefore through transport of fine sediments. A sediment transport modeling study was deemed necessary to examine the transient behavior (migration/deposition/scouring) of sediments in the river.

A one-dimensional, hydraulic/sediment transport model, HEC-6, was developed and calibrated to simulate the sediment transport in Twelvemile Creek/Hartwell Lake for a period of 30 years. The results of the HEC-6 model, including the channel hydraulics, sediment fluxes, deposition and scouring rates of three sediment classes (sand, silt, and clay), and suspended sediment contents along the river channel, were used subsequently as input to the water-quality model for the prediction of PCB transport.

2.0 GENERAL DESCRIPTION OF THE RIVER SYSTEM

A field trip was made on April 28 and 29, 1992, to obtain a first-hand impression of the river system. As shown in Figure 1, the river system includes Twelvemile Creek, Keowee River, and Seneca Creek. In Twelvemile Creek, there are three overflow dams located about 7 miles upstream from the confluence with Hartwell Lake. The first (most upstream) dam is a water supply dam operated by the Easley Water District The other two dams (Woodside I and II) are small hydropower dams owned by the Woodside Company. PCB contamination originated in the 1960s in the upper reaches of Twelvemile Creek (Bechtel 1992). Most of the contaminants had been subsequently transported to the reach downstream of the three overflow dams.

The Woodside Company indicates that sediments trapped in the small reservoirs are flushed out regularly (i.e., monthly at the water supply dam, and twice annually at the two hydropower dams). Therefore, from the hydraulic and sediment transport point of view, it is reasonable to use the most downstream overflow dam (Woodside II) as the upstream boundary of this river system simulation.

The river channel being modeled is the 10-mile stretch of Twelvemile Creek (7 miles) and Hartwell Lake (3 miles) as shown in Figure 1. The upstream boundary of the study reach is about 800 ft downstream of the Woodside II impoundment The downstream boundary is located near the Hwy 37 Bridge crossing south of Treaty Oak Monument in Hartwell Lake.

The reach has a mild slope that averages 0.15 percent. There are a few meanders along the creek and a few places with abrupt changes in the channel cross sections.

The watershed contributing to the flow of Twelvemile Creek at the upstream boundary covers approximately 140 mi^2. Several small tributaries discharge to Twelvemile Creek in the study reach. There are also two major river branches, Seneca Creek and Keowee River, flowing into the main channel in the Hartwell Lake reach. For modeling purposes, river branches and tributaries are treated as inflow points for both flow and sediment supply. A total of six inflow points were used to approximate the river system in the study channel. The drainage basin associated with each of the inflows was delineated from a United States Geological Survey (USGS) 30-minute topographic map (Greenville, South Carolina, 1991). Figure 1 includes the locations of the six inflow points and the sizes of the corresponding drainage basins. The drainage areas and sediment supply characteristics are summarized in Table 1.

The model channel begins at the upstream boundary with discharges from Inflow 1. The channel flow is increased with Inflow 2 in the mid-reach of Twelvemile Creek. Six Mile Creek joins Keowee River before discharging into Hartwell Lake. In the model, Six Mile Creek and Keowee River were simulated independently as Inflows 3 and 4, respectively, because of the different sediment loading characteristics. Finally, Inflow 5 and Inflow 6 (Seneca Creek) add to the main flow at Hartwell Lake in the lower reach. Of all the inflows, only Keowee River (Inflow 4) is assumed to be free of sediment because of the upstream impoundment (Lake Keowee), which traps the sediment loadings. Section 4.4 discusses the inflow hydrographs developed on the basis of these drainage areas.

3.0 MATHEMATICAL MODEL

The HEC-6 computer model, "Scour and Deposition in Rivers and Reservoirs, Version 4.0," (COE 1991) developed by the U.S. Army Corps of Engineers (COE) Hydrologic Engineering Center (HEC), was used to perform the sediment routing computations. HEC-6 is designed to simulate scour and deposition of sediment in rivers and reservoirs by modeling the interactions among the water-sediment mixture, the sediment material forming the stream bed, and the hydraulics of the flow. It is a one-dimensional, quasi-steady flow model, based on the assumption of a uniform, lateral distribution of sediment load across the channel cross section. A one-dimensional model is generally accepted to be adequate in the simulation of flow and sediment transport in rivers, such as Twelvemile Creek, where the transport in the transverse and vertical directions is small compared with the transport in the longitudinal direction. In Hartwell Lake, however, where flow is multidimensional, significant uncertainty likely is associated with the HEC-6 predictions.

The HEC-6 model can simulate the sediment transport for both the noncohesive and cohesive (silt and clay) materials. There are 11 built-in sediment transport functions for noncohesive materials in the HEC-6 model (COE 1991). Yang's streampower method, which is valid for sediment sizes ranging from 0.13 to 7.01 mm, has been adopted to perform the noncohesive sediment transport computations. Yang's method should yield reasonable results for the sediments and hydraulic conditions of Twelvemile Creek

Several bed sediment samples collected in Twelvemile Creek show that there are notable amounts (over 50 percent) of fine materials (grain size of less than 0.062 mm) in the bed sediment. Therefore, the cohesive transport option of HEC-6 was used to more accurately model the transport of fine sediments (silt and clay).

4.0 DATA AND ASSUMPTIONS

4.1 Channel Geometry Data

Twenty-two cross sections were selected, as shown in Figure 1, to represent the 10-mile study reach of Twelvemile Creek and Hartwell Lake. Table 2 lists the corresponding station numbers (as used in the model) for the 22 sections and their relative distances from the downstream boundary. Thirteen of the cross sections (identified with "*" in Table 2) were developed partially based on field survey data obtained by Bechtel. Modifications and extrapolations were used during the development of these cross-sectional data to fill in the missing data and other anomalies. The remaining cross sections were estimated with the aid of USGS 7.5-minute topographic maps (Clemson Quadrangle and Six Mile Quadrangle, South Carolina, photorevised 1980).

Because of the nature of the survey data acquired (such as the lack of reference elevations and measurements for stations near the upstream boundary), a number of assumptions were made to develop the cross-sectional data used in the model.

The elevations of the channel sections were derived from the estimated water surface levels of the transects at the time they were surveyed. These water surface levels were estimated initially by assuming that the average operating lake level elevation of Hartwell Lake was 660 ft (the water surface elevation measured at the dam of Hartwell Lake was 660.02 ft during the 1992 Bechtel field survey). The elevations of the sections near the upstream end of the study reach were derived initially by extrapolation. They were later calibrated according to the tailwater level of the Woodside II overflow dam and the historical depositions recorded by COE at six stations along the Twelvemile Creek reach (COE 1992). The calibration is further discussed in Section 5.0

The longitudinal channel profile (invert elevations versus distances along the river) as used in the final simulation is shown in Figure 2. Figure 3 depicts the profile of a typical channel cross section (Station J). The solid segments shown in Figure 3 represent data interpreted from the 1992 survey data or from the USGS topographic maps, whereas the shaded segments are derived using interpolations and extrapolations.

4.2 Bed Material and Sediment Gradation Data

Bechtel collected bed sediment samples at 11 transects of Twelvemile Creek The median grain sizes of the sediment samples vary from 0.0075 to 0.145 mm Over half of the sediment samples have more than 50 percent of the grains in the silt and clay ranges (finer than 0.062 mm). The cohesive sediment option of HEC-6 was therefore used to simulate the transport of the fine materials.

The sediment size distribution curves were used directly as the bed gradation data of the model channel. For stations such as D, T6, and T12, where no sediment samples were collected, interpolations based on the distributions of the adjacent transects were used. For stations located outside of the survey area (upstream of P), bed gradation was assumed to be the same as that of Station P.

4.3 Sediment Supply

HEC-6 requires that sediment supply at each of the inflow points be input. Sediment supply is input as a rating curve in which sediment discharge is expected as a function of river flow rate. Preliminary sediment loading estimates were derived from the sediment transport capacity of the 3.6-mile channel reach of Twelvemile Creek, upstream of the three overflow dams. It was assumed that the long-term sediment supply characteristics of this upstream channel would be similar to that of the study reach. Yang's method was used to calculate the transport capacities by fraction of the sediment classes (fine sand to fine gravel) for the given hydraulic conditions of the channel. For finer materials (very fine sand to clay), sediment supply was assumed to be the same as that of the fine sand class.

This sediment supply was modified during model calibrations to match the suspended sediment concentrations measured in Twelvemile Creek (1992 Bechtel field survey) and to match the channel profile based on the COE-measured cross-sectional data at six stations along Twelvemile Creek in 1963 and 1973 Details of the calibration are discussed further in Section 5 0. The sediment supply rating curve adopted in the study is shown in Table 3

4.4 Mean Daily Flow Generation

The HEC-6 model requires that time series of continuous flows at the boundaries of the modeled system be input. The drainage area above the downstream boundary of the model domain is in excess of 600 mi^2. No long-term continuous flow records exist for the watersheds contributing flows to the modeled system Therefore it was necessary to generate representative long-term historical flow sequences for the period of the intended simulation

The procedures adopted for generating the flows for the modeling consisted of 1) extending the historical monthly records of the available stream gauging stations in the project vicinity using multiple regression, 2) distributing them into daily records, and 3) generating representative flow sequences for tributary watersheds by scaling these extended records with respective drainage-area ratios.

Mean daily flows of five nearby stream gauging stations were obtained from the USGS. The pertinent station information is given in Table 4 The Twelvemile Creek Near Liberty gauge station had continuous records from August 1954 to September 1964. Gauging began at this station again in July 1989, and the station is still active. The Keowee River near Newry station had records from December 1939 to June 1961, but is presently inactive Figure 4 shows a plot of the annual flows at these stations for the period of record. The annual flows, expressed as inches per square mile of drainage area, are also plotted as shown in Figure 5. Annual flow series are closely correlated at the stations, as can be observed in Figures 4 and 5.

The continuous flow record for the station on the Reedy River near Ware Shoals is the longest, extending from April 1939 to September 1991; it formed the basis for extending and filling in the missing periods of the records of the other stations. Various multiple-regression relationships were explored; flow generators were selected using the monthly flows at these stations and at those that gave the highest coefficient of determination. Table 5 summarizes the regression equations which were developed using the monthly sums of the mean daily flows of the respective stations with a concurrent period of record. The extended monthly flows and their statistics are given in Tables 6 and 7 for Twelvemile Creek and Keowee River, respectively.

The daily flow records for Twelvemile Creek and Keowee River for the periods when monthly flows were generated were obtained by scaling the daily flows of Reedy River with the respective monthly flow ratios. The mean daily flows for the six watersheds (Figure 2) of the modeling domain were then derived by scaling the extended flows of Keowee River and Twelvemile Creek gauges with the respective drainage-area ratios.

For assessment of long-term sediment transport, a representative 30-year flow period (1961-1991) was selected. Within this 30-year period, flows occurred in the first 4 years and the last 2 years, while relatively low flows occurred in the middle 24 years.

The flow hydrographs used in the model runs were approximated from the daily flows in order to reduce the total number of run steps in the simulations During low-flow periods, the original daily hydrographs were simplified using constant flow rates (which were averages of the daily values) for the entire low-flow period. Figure 6 shows the 30-year hydrograph generated for 1961 to 1991 for upper Twelvemile Creek

4.5 Downstream Boundary Conditions

The downstream boundary conditions for the HEC-6 modeling were derived from the recorded operating levels of Hartwell Reservoir Daily reservoir levels from 1962 to 1992 and the corresponding lake inflow and outflow data were available A detailed analysis of this data indicated that operation varies from one year to another. A constant rating curve for the downstream boundary water surface elevations was therefore determined approximately for the stages ranging from 646.0 to 663.5 ft (roughly the lower and upper limits of the operating levels of Hartwell Lake from 1962 to 1992). The rating curve is shown in Table 8.

5.0 HYDRAULIC AND SEDIMENT CALIBRATION

The HEC-6 model was calibrated for flow and sediment transport using site-specific measurements of the hydraulic and sediment parameters As shown in Figure 2, the headwaters of Hartwell Lake fluctuate between Stations Q and T17; sediment deposition and scouring are expected to occur in this sub-reach. The sedimentation in this sub-reach is also sensitive to the sediment supply from its upstream watershed. Therefore, the main calibration parameters were the sediment supply and the channel profile near the upstream boundary (T15 to T19). Several iterations were made to calibrate the model. The following sections discuss the data used and the calibration

5.1 Available Data for Model Calibration

Data for model calibration include the suspended sediment samples collected by Bechtel during the April - May 1992 sampling and the data collected by COE previously.

During the field survey of 1992, Bechtel collected water column samples at five stations along Twelvemile Creek: the Hwy 37 Bridge (near T1), Hwy 93 Bridge near (B), Hwy 133 Bridge (near J), Madden Bridge (near O), and Maw Bridge (near T15). Analysis of the samples indicates that the total suspended solid concentrations (assumed to consist of sediment only) vary from 5.6 mg/L in the most downstream station (near T1) to 46 mg/L in the most upstream station (near T15). Although the flow rates in the creek were not measured at the time of the survey, flow was estimated to range from 200 to 500 cfs in Twelvemile Creek. This data set is primarily used to calibrate the sediment supply, especially of the fine materials.

COE conducted two hydrographic surveys, one in 1963 and the other in 1973, on six sections of Twelvemile Creek and Hartwell Lake to investigate sedimentation rates (Reference 3). COE concluded that at the upstream locations near T16, the average deposition rate was about 3 ft over the 10-year period of 1963 - 1973. There was very little change in the bed profile (insignificant deposition or scouring) for the stations in the mid-reach and the lower reach (i.e., downstream of T12) The hydraulic and sediment conditions in Twelvemile Creek were changed in the 1980s with the rehabilitations of the Woodside I and II overflow dams and sediment sluicing from the power pools Nevertheless, it was assumed that the long-term sediment supply and hydraulic characteristics remained unchanged because the sediment storage capacities of these reservoirs are relatively small and would therefore have negligible effect on the sediment regime.

5 2 Hydraulic and Sediment Calibrations

A 10-year simulation (1963 - 1973) was performed using an initial channel profile derived from the COE bathymetric survey data of 1963 and estimates of sediment supply and the flow hydrographs for this period. The predicted depositions at the end of the simulation were then compared with the increases in channel bottom elevations measured by COE from 1963 to 1973. The sediment supply contents in each sediment class were then systematically reduced until the predicted depositions were in the same order of magnitude as the measured values (approximately 3 ft). Figure 7 shows the simulated 1973 channel bottom profile with the COE 1963 and 1973 data.

The predicted suspended sediment concentrations in the channel varied from about 10 mg/L in the Hartwell Lake area (T1) to 100 mg/L in the mid-reach of Twelvemile Creek (O) at low flow conditions. These values are slightly higher than the observed suspended sediment concentrations, which range from 5.6 mg/L to 46 mg/L

Next, a calibration run was performed for the 1963 - 1991 period to predict the bottom profile for 1991, using the revised sediment supply rating curve The predicted profile for 1991 showed scouring at the upstream boundary Subsequently, the channel profile (derived from the 1992 survey data) was adjusted, especially the bed slope and elevations in the upper reach, until the predicted scouring at the upstream boundary area was minimized, in conformance with the field observations that the selected upstream boundary is presently a stabilized section The bed profile thus calibrated (as shown in Figure 3) was then used as the initial channel condition in the final HEC-6 runs.

6.0 SEDIMENT ROUTING AND RESULTS

The calibrated HEC-6 model was used to simulate the sediment transport in Twelvemile Creek/Hartwell Lake in the next 30 years assuming that the historic hydrologic flow regime will be repeated and the sediment supply to the system will remain the same. In summary, the final simulation run included the following features:

- A calibrated channel profile, representing the initial (1992) channel conditions
- A calibrated sediment supply, at the six inflow points
- An approximate rating curve for the operating levels of Hartwell Lake (646.0 to 663.5 ft), to present the downstream boundary conditions
- The inflow hydrographs from 1961 to 1990 to forecast the sediment movement for the next 30 years
- Yang's equation as the transport function for noncohesive materials, and the transport option for cohesive materials in HEC-6

The final sediment routing results are presented in Figure 9 and discussed below.

10-Year Simulation

As shown in Figure 8, after 10 years into the simulation, scouring of approximately 1 to 2 ft was predicted in the two most upstream sections (T18 and T19). Depositions from 2 to 7 ft were estimated in the reach between Stations O and T15, whereas the downstream stretch (downstream of Station M) showed little change. This deposition pattern can be explained by the backwater effect of Hartwell Reservoir Backwater effect is defined as the increase in the flow depth of a river reach caused by a downstream control structure such as a spillway. The location where the backwater effect diminishes is referred to as the extent of the headwater of the control structure. It is usually characterized by more substantial reduction in the channel flow velocity. Deposition is anticipated both upstream of the headwater and near the headwater where flow velocity is effectively reduced Scour is more likely to develop upstream of the headwater

As discussed in Section 4.5, the operating levels of Hartwell Lake fluctuate between elevation 646.0 to 663.5 ft in the model. Sediment redistribution is expected to occur in the upper reach where the invert elevations are above 646 ft, although some deposition may extend to a reach slightly downstream. Model results showed that sediments coarser than clay were deposited upstream of Station M (invert elevation of 640 1 ft). Deposition of clay occurred mainly in the lower reach of Twelvemile Creek (from T6 to L). Only a moderate amount (approximately 50 percent of the supply) of clay was carried farther downstream through the model boundary (T1) of the channel

20-Year Simulation

Scouring of about 1 to 2 ft was predicted in the two most upstream sections at the end of 20 years in the simulation. Deposition was predicted in the reach from Station N to Station T15, with the maximum deposition depth increasing to approximately 11 ft Similar to the 10-year results, the downstream bottom profile (downstream of Station M) showed little change.

30-Year Simulation

At the end of the 30-year simulation, scour depths of about 2 ft were predicted in the upstream sections. This further confirmed that the upstream boundary was relatively stable and the calibrated sediment supply was reasonable for this river system.

Maximum deposition depths of about 13 ft were estimated in the mid-reach near the Station N area. The invert elevation of Station N was relatively close to the lower end of the reservoir operating levels, suggesting that the flow velocity of the reach downstream of Station N was low. Therefore, the lower reach downstream of Station M again had only small deposition depths.

In general, the model predicted that most of the sediments were accumulated within the mid-reach of Twelvemile Creek near the headwater elevations (varying from 646.0 to 663.5 ft). Deposition of small quantities of the finer sediments was predicted in the lower reach of Twelvemile Creek (T6 to L). The predicted deposition depths increased with time, and the slope of the deposition delta also became steeper with time.

Time histories of the predicted channel bottom elevations at an upper-reach station (T18), a mid-reach station (T12) and a lower-reach station (M) of Twelvemile Creek are plotted in Figure 9. The predicted bottom elevation at Station T18 showed a gradual degradation of 1 ft in the first 4 years of the simulation. The bed elevation then retained a relatively constant value until the last 2 years of simulation when it dropped another 1 ft. The degradation pattern at this location illustrated two features: (1) the estimated scour depths were directly related to the inflow rates shown in Figure 6, and 2) the insignificant degradation over the 30-year period suggests that the selected upstream boundary was relatively stable as indicated by the field observations.

At Station T12 (in the mid-reach), the estimated bottom elevations were characterized by sediment depositions as shown in Figure 9. Approximately 10 ft of deposition was built up during the first 15 years of the simulation In the next 15 years, sediment deposition was relatively minor, with the channel bottom attaining a more or less equilibrium elevation. The deposition pattern at this station demonstrated the following hydraulics and sediment transport characteristics: 1) because the upper reach was relatively stable, a majority of the deposited materials would have to have originated from the sediment loadings carried from the upstream watersheds, 2) the deposition rate in this location was not solely dependent on the inflow rates as in Station T18, 3) deposition apparently began in the upstream end of the deposition delta, (T15) and eventually advanced downstream towards Station M

As shown in Figure 9, only minor deposition was predicted for Station M (shortly downstream of the lower end of the headwater). Sediments accumulated at a much slower rate compared with that of T12. The sudden increase in sediment deposition in the last 2 years of the simulation was caused by the higher inflow rates (Figure 7), which produced more scouring in the upper reach. The bottom elevation at Station M was expected to continue to rise beyond the 30-year simulation period, and the sedimentation delta was expected to extend farther downstream with time.

7.0 GENERATION OF INPUT DATA FOR WASP 4

The water quality model WASP4, used to simulate the fate and transport of PCBs in the Twelvemile Creek and Hartwell Lake system, requires as inputs hydrodynamic data, and solids concentration and flux data. A Bechtel in-house computer program was developed to post-process the HEC-6 model output to obtain the data relevant to the WASP4 model. The following summarizes the data deduced from the HEC-6 results for each sub-reach at each time step:

Geometric Data

- Distance (of the sub-reach) between centroids
- Cross-sectional area of the upstream section
- Depth of water at the upstream section
- Area of water surface
- Average bottom area of the sub-reach

Hydrodynamic Data

- Flow Rate
- Flow velocity at the upstream section

Solids Data

- Fluxes of sand, silt, and clay at the upstream section
- Deposition/scouring rates for sand, silt, and clay
- Concentrations of suspended sand, silt, and clay

In addition, a rating curve for the sediment supply at the various inflow points (with the exception of Keowee River, which was assumed to be free of sediment) was provided

8.0 CONCLUSIONS AND RECOMMENDATIONS

- Results of the sediment routing indicate that the sediment load to the Twelvemile Creek/Hartwell Lake system will eventually be deposited in the mid-reach of Twelvemile Creek (Stations M to T15) over the next 30 years In the lower reach from Station T6 to Station L, there will be small amounts of deposition of the finer sediments. About 50 percent of the total clay supply from the watersheds will be transported through this system and pass the downstream boundary (T1) of the model The depositional pattern is primarily governed by the backwater effect of the reservoir, which operates at water levels varying from elevation 646.0 ft for low flows to 663.5 ft for high flows.

- The predicted sediment transport in Twelvemile Creek/Hartwell Lake was indirectly confirmed by the 1991 PCB field data (Bechtel 1992) The data indicated low PCB concentrations (about 1 ppm) in the upper reach of Twelvemile Creek; moderate concentrations (about 4 ppm) in the mid-reach shortly downstream of Station T15 and in the lower reach area around Stations T6 and H; and high PCB levels (about 8 ppm) at the downstream end of the mid-reach near Station M. Assuming PCBs are associated with the fine-grained sediment, these observed variations of PCB concentrations along the river channel agreed well with the model prediction of the deposition pattern.

- The predictive capabilities of the model can be further enhanced with additional field data including essential bathymetry data and surveyed reference elevations of the selected sections. Supplementary sections should be introduced at areas with complicated geometry to better define the model channel. Additional suspended sediment concentration measurements with associated flow data would be useful in refining the model calibration.

- The hydraulics of the channel reaches are very important in determining the sediment transport behavior. Because the downstream boundary conditions have significant impact on upstream hydraulics, a more realistic boundary condition (i.e., variable reservoir levels) should be used to improve the prediction of sediment movements in the river.

- The hydrodynamic regime in the Hartwell Lake area (downstream of Station T6) is apt to be multidimensional Should future work focus on sediment and PCB modeling within Hartwell Lake, it is recommended that a two-dimensional sediment transport model be used for predicting the depositional patterns in the lake area

REFERENCES

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2. U.S. Army Corps of Engineers (COE) Hydrologic Engineering Center, 1991. "HEC-6 Scour and Deposition in Rivers and Reservoirs, User's Manual," distributed by West Consultants, Inc., Carlsbad, California (June).

3. COE Hydraulics Section, 1992. Memorandum: "Sedimentation in Hartwell Lake" (September 9).

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Table 1. Drainage Areas of Inflow Points

Inflow (Section)[a]	Drainage Area (mi^2)	Sediment Supply
Inflow 1: Station[b] 54.1 (T19)	139.8	yes
Inflow 2: Station 37.9 (P)	14.2	yes
Inflow 3: Station 22 1 (H)	21.8	yes
Inflow 4 (Keowee River): Station 17.4 (D)	455.0	no
Inflow 5: Station 15.0 (C)	8.0	yes
Inflow 6 (Seneca Creek): Station 4.0 (A)	10.7	yes

[a]Sections are shown in Figure 1.
[b]Station numbers are discussed in Section 4.1 and in Table 2.

Table 2. Model Station Numbers and Distances from Downstream Boundary

Section[a]	Model Station Number	Distance From Downstream Boundary (ft)
T1[b]	0.0	0
A[b]	4.0	4,000
B[b]	12.0	12,000
C[b]	15.0	15,000
D	17.4	17,400
T6	18.6	18,600
H[b]	22.1	22,100
I[b]	24.4	24,400
J[b]	26.4	26,400
K[b]	27.4	27,400
L[b]	29.4	29,400
M[b]	30.1	30,100
N[b]	32 3	32,300
O[b]	34.9	34,900
T12	37 0	37,000
P[b]	37.9	37,900
Q	38 9	38,900
T15	42.7	42,700
T16	45.1	45,100
T17	49.1	49,100
T18	52.1	52,100
T19	54.1	54,100

[a]Sections are shown in Figure 1
[b]Survey data available

Table 3. Sediment Supply Rating Curve

Inflow Rate (cfs)	Sediment Load (tons/day)
10	1
100	45
200	123
500	411
750	691
1,000	991
2,500	2,968
5,000	7,878
7,500	12,778

Table 4. USGS Streamflow Measuring Stations in Project Vicinity

USGS Station ID	Station Name	Drainage Area (mi^2)	Latitude	Longitude	Period of Record
2162500	Saluda River Near Greenville, SC	295	34°50'32"	82°28'51"	Apr. 1942 - Sept. 1978 Mar. 1990 - present
2165000	Reedy River Near Ware Shoals, SC	236	34°25'02"	82°09'10"	Apr. 1939 - present
2185200	Little River Near Walhalla, SC	72	34°50'11"	82°58'48"	Mar. 1967 - present
2185500	Keowee River Near Newry, SC	455	34°44'20"	82°51'50"	Dec. 1939 - June 1961
2186000	Twelvemile Creek Near Liberty, SC	106	34°48'05"	82°44'55"	Aug. 1954 - Sept. 1964 July 1989 - present

Table 5. Multiple Regression Equations

Equation	R^2
Saluda = 202.07+1.25*Reedy	0.71
Keowee = 273.62+0.529*Reedy +1.616*Saluda	0.91
Twelvemile = 9.11+0.099*Reedy +0.091*Saluda +0.0815*Keowee	0.77

[a]R^2 = coefficient of determination.

Table 6 Combined flows at Twelve Mile Creek near Liberty, SC [ft3/sec]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1939	-	-	-	209	176	140	151	251	125	111	113	93	152
1940	126	197	178	177	119	95	123	391	131	75	128	148	157
1941	141	108	154	149	93	84	231	106	72	66	79	165	121
1942	135	272	336	151	197	150	135	164	151	98	94	274	180
1943	363	278	297	271	224	184	273	147	109	88	108	118	205
1944	178	280	448	340	202	133	116	102	106	105	114	121	187
1945	137	218	215	228	159	100	126	118	156	99	116	268	162
1946	553	445	364	252	283	155	172	147	104	120	141	124	238
1947	322	169	191	213	132	142	97	85	68	127	225	143	159
1948	155	290	337	261	158	113	187	229	155	87	397	278	221
1949	295	336	249	318	295	227	402	315	336	360	275	238	304
1950	252	217	234	205	152	232	218	140	229	142	97	187	192
1951	133	158	226	237	142	149	98	81	91	67	129	339	154
1952	187	236	617	300	195	140	83	155	86	67	92	118	190
1953	233	358	309	178	242	170	138	97	102	77	86	257	187
1954	416	233	251	224	162	119	73	54	37	38	67	118	149
1955	117	257	113	179	196	94	83	54	42	56	66	54	109
1956	55	337	198	306	131	82	95	55	68	71	107	138	137
1957	207	274	185	299	110	115	68	63	116	136	240	207	168
1958	224	281	272	341	331	196	259	164	106	105	109	134	210
1959	136	197	225	318	216	237	162	132	162	215	138	195	194
1960	255	401	412	373	231	189	156	196	215	188	128	142	241
1961	188	467	259	336	199	344	230	263	130	114	147	555	269
1962	260	275	361	405	206	194	135	121	90	136	174	162	210
1963	231	181	570	257	202	141	174	106	128	97	142	173	200
1964	359	255	412	578	268	177	176	203	144	515	249	315	304
1965	272	382	445	400	281	342	216	188	146	219	156	132	265
1966	178	408	365	205	245	158	129	144	173	171	214	176	214
1967	247	226	230	162	172	252	193	283	175	159	184	383	222
1968	352	217	314	233	230	265	254	139	116	165	221	196	225
1969	262	346	310	441	257	263	163	196	266	178	195	220	258
1970	207	243	227	235	153	126	96	164	102	158	177	135	169
1971	217	349	332	235	248	161	161	206	158	206	272	377	243

Table 6. Combined flows at Twelve Mile Creek near Liberty, SC [ft3/sec]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1972	412	276	251	225	304	315	210	205	125	141	204	331	250
1973	272	390	466	499	451	330	231	177	203	149	139	277	299
1974	422	398	280	379	268	195	187	233	148	130	139	158	245
1975	216	328	559	317	357	311	242	171	318	308	304	235	306
1976	380	297	339	311	329	319	205	144	143	298	183	329	273
1977	257	194	386	402	195	152	109	113	234	221	274	249	232
1978	445	259	284	213	274	189	141	220	123	131	147	176	217
1979	328	398	362	567	425	319	319	186	174	171	230	165	304
1980	290	223	573	435	317	223	175	164	196	205	223	180	267
1981	161	245	199	202	174	160	160	161	107	158	151	249	177
1982	475	382	249	231	214	204	187	185	153	156	175	264	240
1983	235	315	326	337	248	194	144	135	150	154	184	432	238
1984	240	364	370	289	355	198	300	279	158	177	168	206	259
1985	192	474	227	177	171	146	198	227	156	154	289	215	219
1986	170	160	208	154	150	118	107	134	108	222	236	229	166
1987	277	309	373	263	180	175	144	138	129	119	151	202	205
1988	288	205	202	207	133	118	116	112	168	131	158	147	165
1989	160	185	310	203	200	142	292	109	114	293	139	189	195
1990	275	343	499	222	180	116	127	94	105	183	107	117	197
1991	184	165	207	202	275	194	145	290	151	183	107	117	185
Combined Flow Statistics													
Mean	251	285	314	280	223	185	172	165	143	157	168	210	212
StDev	103	87	115	101	77	71	69	70	59	83	68	94	49
Max	553	474	617	578	451	344	402	391	336	515	397	555	306
Min	55	108	113	149	93	82	68	54	37	38	66	54	109
Recorded Data Statistics (August 1954-September 1964; July 1989-December 1991)													
Mean	208	286	309	318	212	173	162	136	115	139	129	177	193
StDev	80	89	140	107	61	72	67	77	47	71	45	121	44
Max	359	467	570	578	331	344	292	290	215	293	240	555	269
Min	55	165	113	179	110	82	68	54	37	38	66	54	109

Table 7. Combined flows at Keowee River near Newry, SC [ft3/sec]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1939	-	-	-	1404	1205	987	1049	1657	896	809	824	433	1029
1940	597	1062	919	1207	686	510	778	2493	1001	346	719	982	942
1941	928	611	866	950	535	427	1454	651	373	295	416	1079	715
1942	808	1743	1808	917	1233	1042	886	1017	977	606	557	1909	1125
1943	1965	1690	1742	1766	1418	1240	1825	1007	713	545	610	658	1265
1944	1080	1728	2765	2002	1218	780	704	583	702	608	694	732	1133
1945	785	1249	1254	1417	1000	622	769	686	746	610	729	1589	955
1946	3505	2861	2404	1618	1846	958	1104	810	613	631	845	736	1494
1947	1979	1037	1057	1387	816	906	521	458	368	710	1188	808	936
1948	892	1780	2013	1469	912	625	1480	1830	1192	543	2751	1749	1436
1949	1897	1968	1534	2090	1818	1460	2842	2166	2078	2103	1636	1550	1929
1950	1606	1359	1510	1244	905	1564	1506	930	1798	832	467	1111	1236
1951	814	957	1464	1550	918	937	598	426	422	393	912	2297	974
1952	1184	1455	3848	1848	1193	848	340	972	490	342	596	777	1158
1953	1551	2331	1985	1128	1611	1147	966	617	660	454	555	1910	1243
1954	2714	1618	1566	1396	1065	748	395	289	188	202	355	831	947
1955	650	1544	638	1249	1329	575	624	625	325	345	341	317	714
1956	302	1912	1144	1831	1003	539	696	365	459	483	486	927	846
1957	1126	1991	1434	2515	847	1129	636	351	712	1227	1965	1795	1311
1958	1590	1792	1624	2015	1975	963	1615	891	516	544	508	575	1217
1959	1009	1077	1170	1572	1757	1693	1091	641	850	1497	1027	1169	1213
1960	1457	2536	2182	2088	1260	895	837	1033	836	1054	703	700	1298
1961	891	2327	1582	1668	994	1857	1825	2073	1375	1029	1233	3060	1660
1962	2157	2137	2641	3285	1667	1618	1118	926	808	1018	1149	1081	1634
1963	1457	1311	3180	1580	1788	1436	1401	949	932	818	971	1183	1417
1964	1986	1846	2637	3405	2020	1528	1610	1404	1252	3353	1666	2053	2063
1965	1823	2503	2844	2612	1900	2205	1451	1301	1015	1506	1055	916	1761
1966	1173	2637	2337	1375	1666	1093	892	935	1106	1168	1454	1163	1416
1967	1590	1453	1509	1076	1152	1725	1323	1944	1218	1103	1238	2501	1486
1968	2281	1470	2079	1582	1553	1740	1561	957	801	1147	1423	1312	1492
1969	1649	2229	1998	2803	1721	1757	1123	1347	1798	1227	1345	1487	1707
1970	1418	1617	1487	1551	1037	889	675	1116	711	1062	1184	918	1139
1971	1428	2192	2074	1540	1607	1069	1064	1350	1070	1339	1783	2464	1582

Table 7 Combined flows at Keowee River near Newry, SC [ft3/sec]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1972	2570	1766	1630	1467	1903	1965	1390	1301	853	949	1349	2237	1615
1973	1734	2520	2982	3217	3016	2221	1574	1229	1198	1023	953	1895	1964
1974	2742	2611	1855	2507	1805	1332	1268	1560	1011	893	952	1057	1633
1975	1434	2023	3495	2121	2294	2093	1617	1156	2005	1994	2006	1578	1985
1976	2496	1980	2140	2045	2153	2160	1362	984	967	1884	1224	2096	1791
1977	1652	1283	2466	2609	1305	1018	761	775	1615	1413	1818	1683	1533
1978	2833	1753	1849	1411	1813	1261	967	1446	854	918	1029	1206	1445
1979	2121	2547	2325	3568	2710	2067	2066	1262	1193	1174	1530	1137	1975
1980	1889	1490	3607	2767	2057	1487	1195	1129	1323	1378	1490	1225	1753
1981	1111	1621	1342	1360	1192	1103	1106	1112	782	1096	1051	1642	1210
1982	3012	2450	1643	1535	1433	1371	1271	1256	1066	1082	1198	1737	1588
1983	1560	2046	2113	2177	1639	1308	1007	955	1048	1072	1248	2750	1577
1984	1592	2338	2377	1888	2285	1334	1956	1826	1095	1206	1156	1383	1703
1985	1298	3008	1511	1206	1171	1018	1333	1512	1080	1067	1885	1437	1461
1986	1166	1104	1397	1069	1044	848	784	951	793	1481	1564	1527	1144
1987	1814	2009	2393	1728	1224	1200	1011	971	914	859	1050	1357	1378
1988	1880	1381	1359	1388	941	848	838	816	1152	931	1093	1027	1138
1989	1103	1256	2013	1368	1347	1478	1132	1326	1072	1790	1360	795	1337
1990	2287	2912	3705	2050	1634	1029	956	919	844	1433	1019	1442	1686
1991	1807	1374	1756	2022	2186	1635	1294	1847	1258	1433	1019	1442	1589
	Combined Data Statistics												
Mean	1592	1802	1948	1823	1487	1251	1163	1116	965	1038	1120	1385	1396
StDev	669	556	738	641	516	470	462	482	401	549	485	598	334
Max	3505	3008	3848	3568	3016	2221	2842	2493	2078	3353	2751	3060	2063
Min	302	611	638	917	535	427	340	289	188	202	341	317	714
	Recorded Data Statistics (December 1939 - December 1991)												
Mean	1333	1665	1660	1588	1197	976	1032	897	763	684	860	1120	1147
StDev	745	553	707	405	397	393	589	586	465	454	595	550	280
Max	3505	2861	3848	2515	1975	1857	2842	2493	2078	2103	2751	2297	1929
Min	302	611	638	917	535	427	340	289	188	202	341	317	714

Table 8. Rating Curve for Downstream Boundary Conditions

Downstream Water Surface Elevations (ft)	Flow Rates at Downstream Boundary (cfs)
646.0	< 200
646.0	200
650.0	400
655.0	800
657.0	1000
658.0	1300
659.0	1600
660.0	2000
660.5	2250
661.0	2600
661.5	3000
662.0	3600
662.5	4300
663.0	5450
663.5	7100
663.5	> 7100

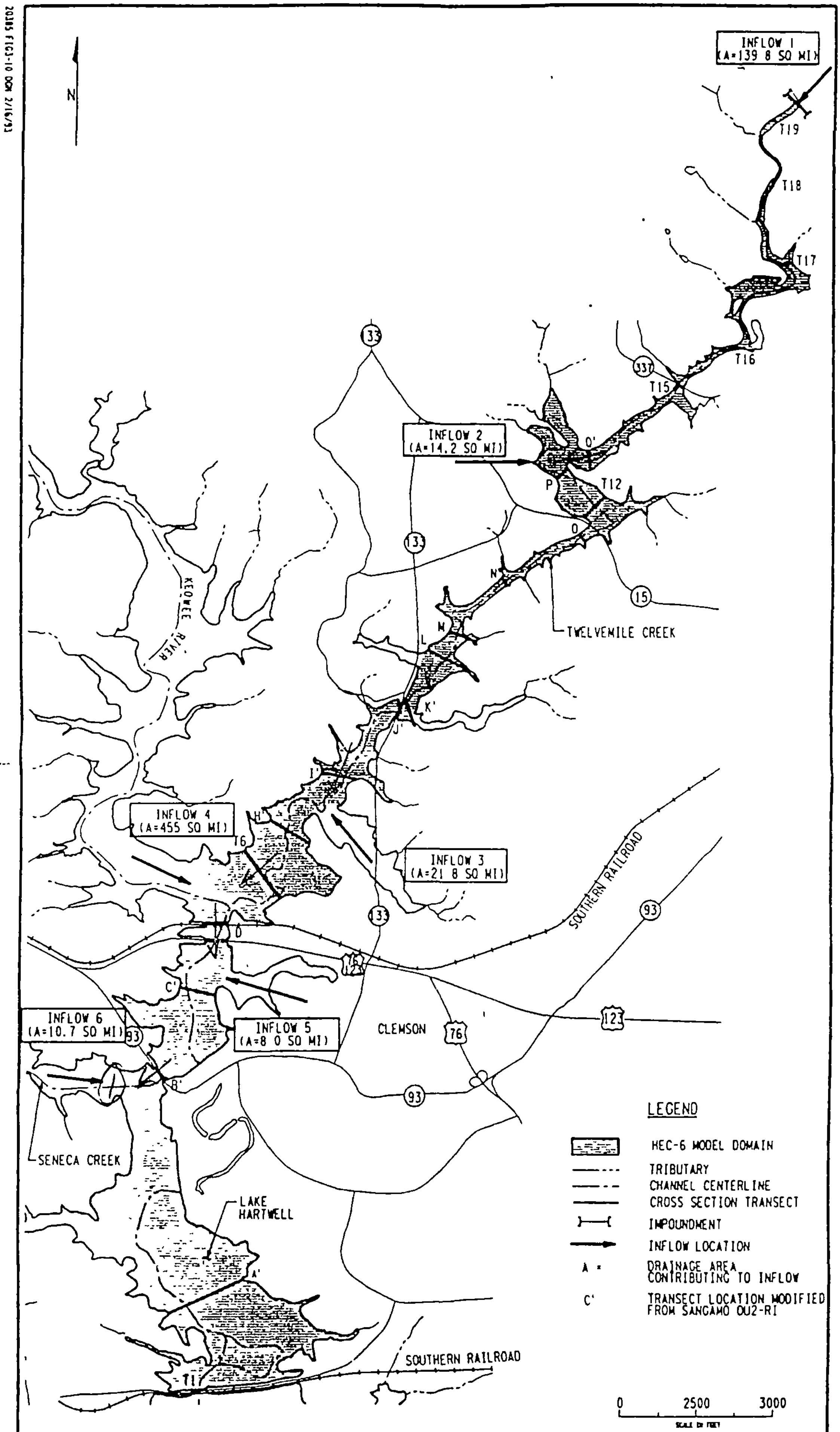

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Figure 1
HEC-6 Model Transect Locations
Sangamo OU-2 RI

Figure 2. Longitudinal profile of the Twelve Mile Creek-Hartwell Lake system

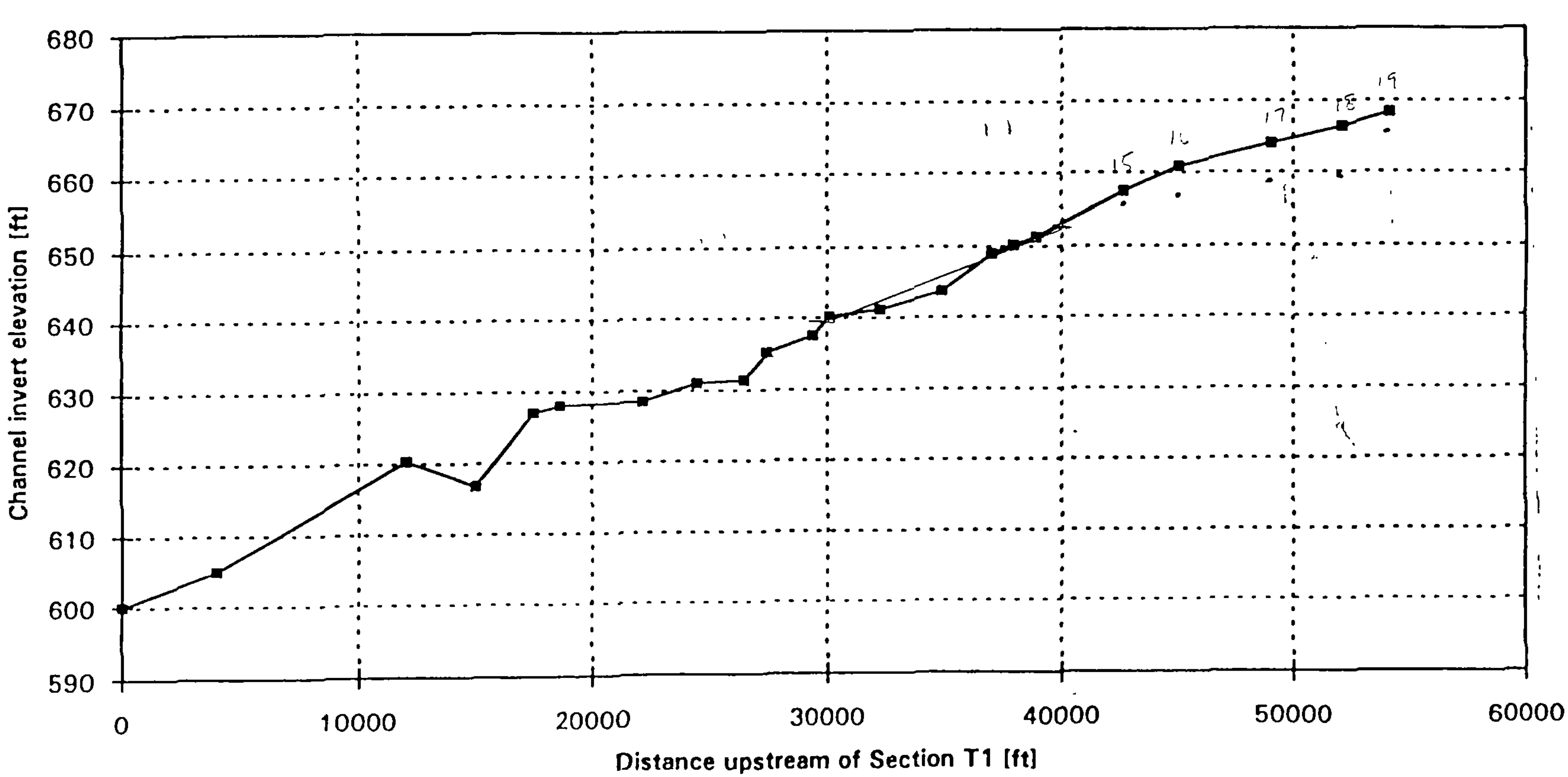

Figure 3. Channel cross section at Transect J

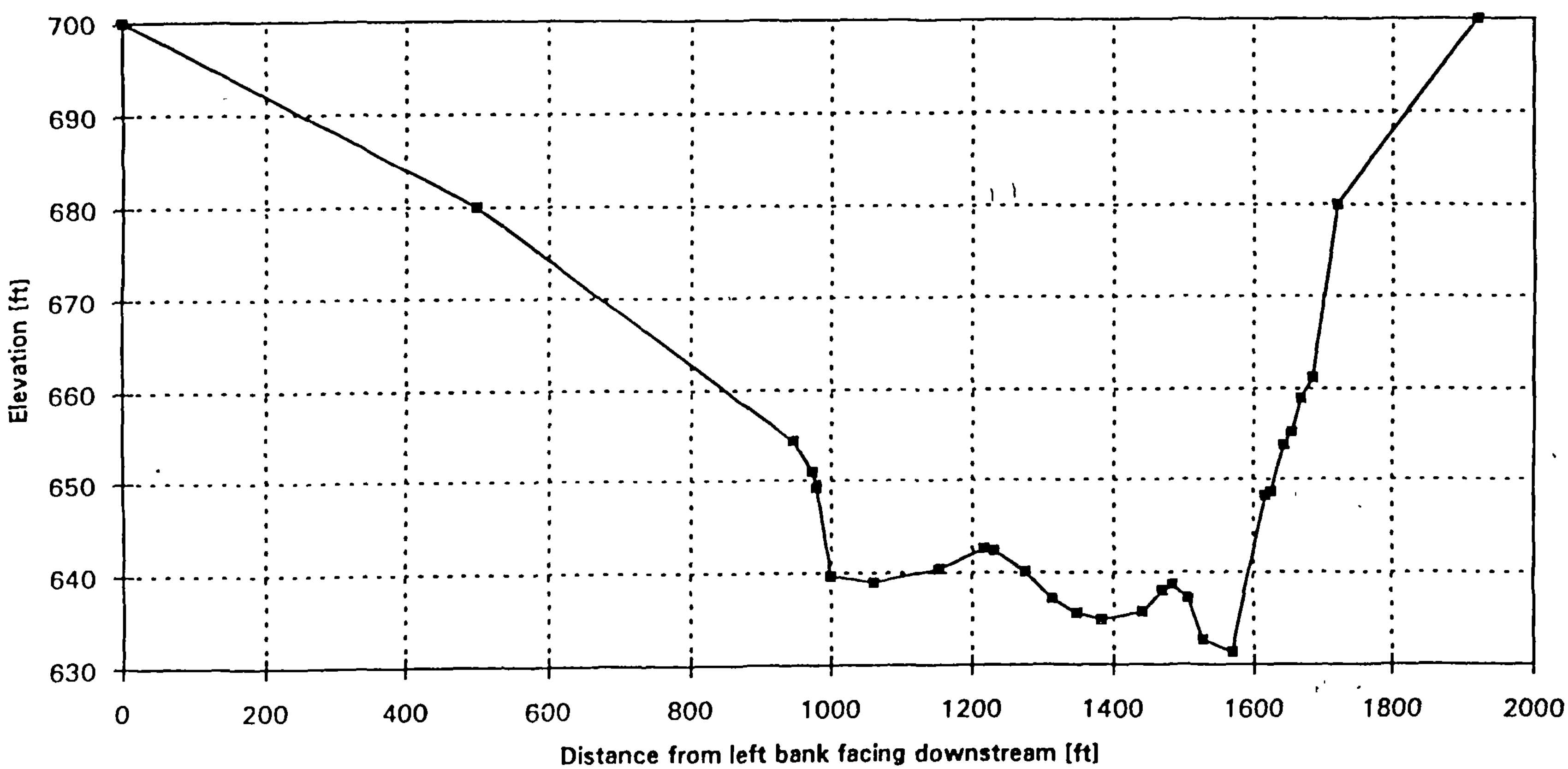

Figure 4. Annual flows for regional drainages

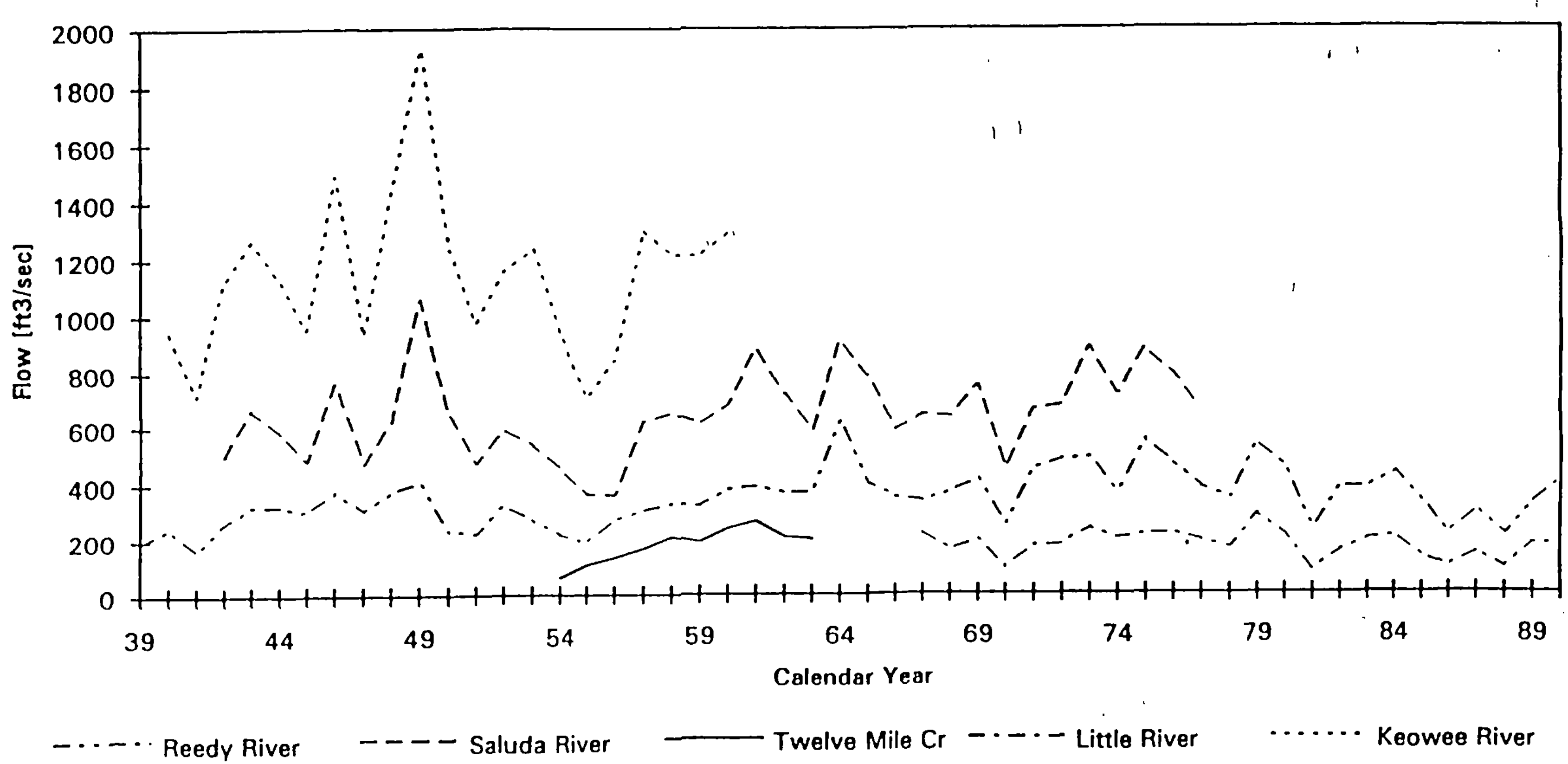

Figure 5. Unit area annual flows for regional drainages

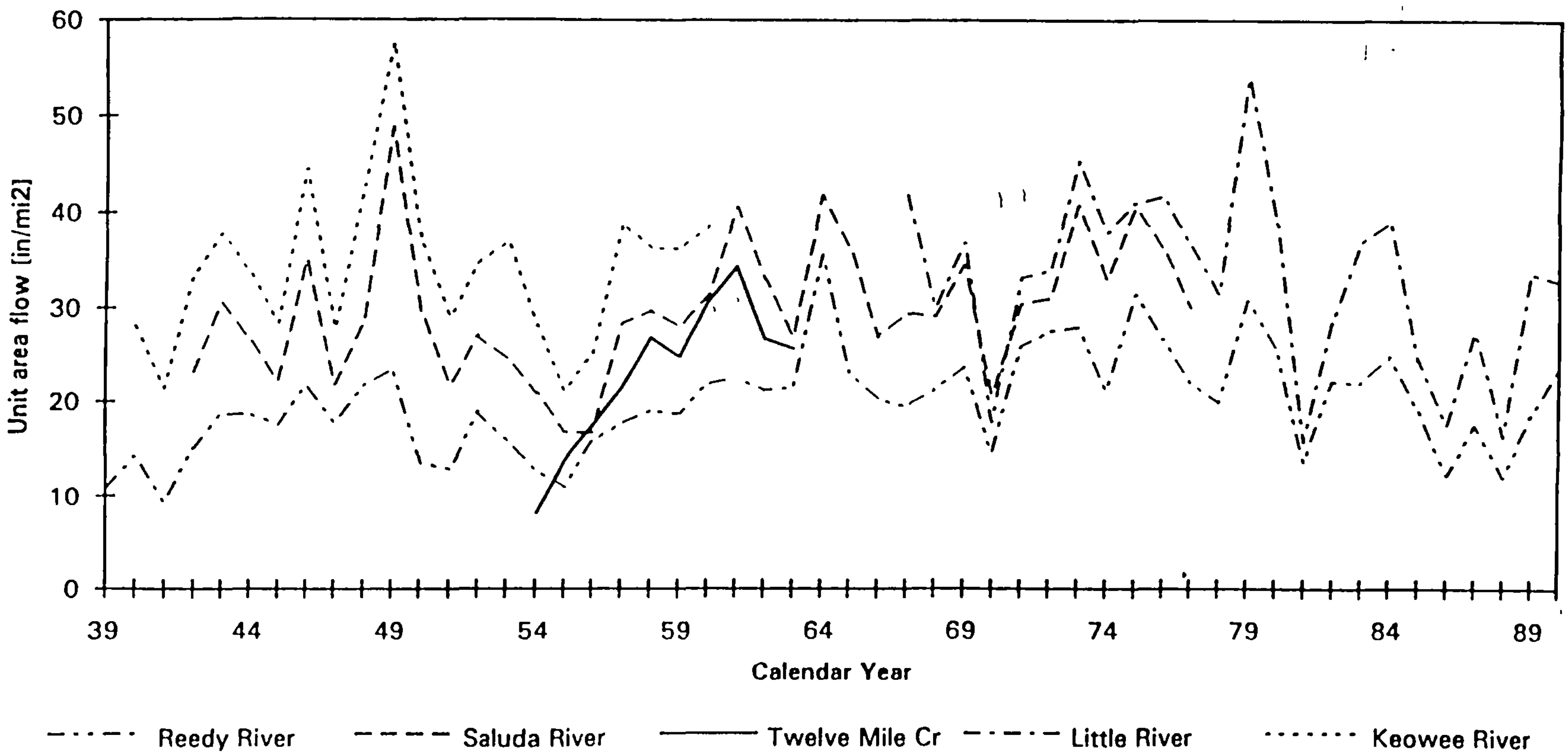

Figure 6. Thirty-year hydrograph for Twelve Mile Creek

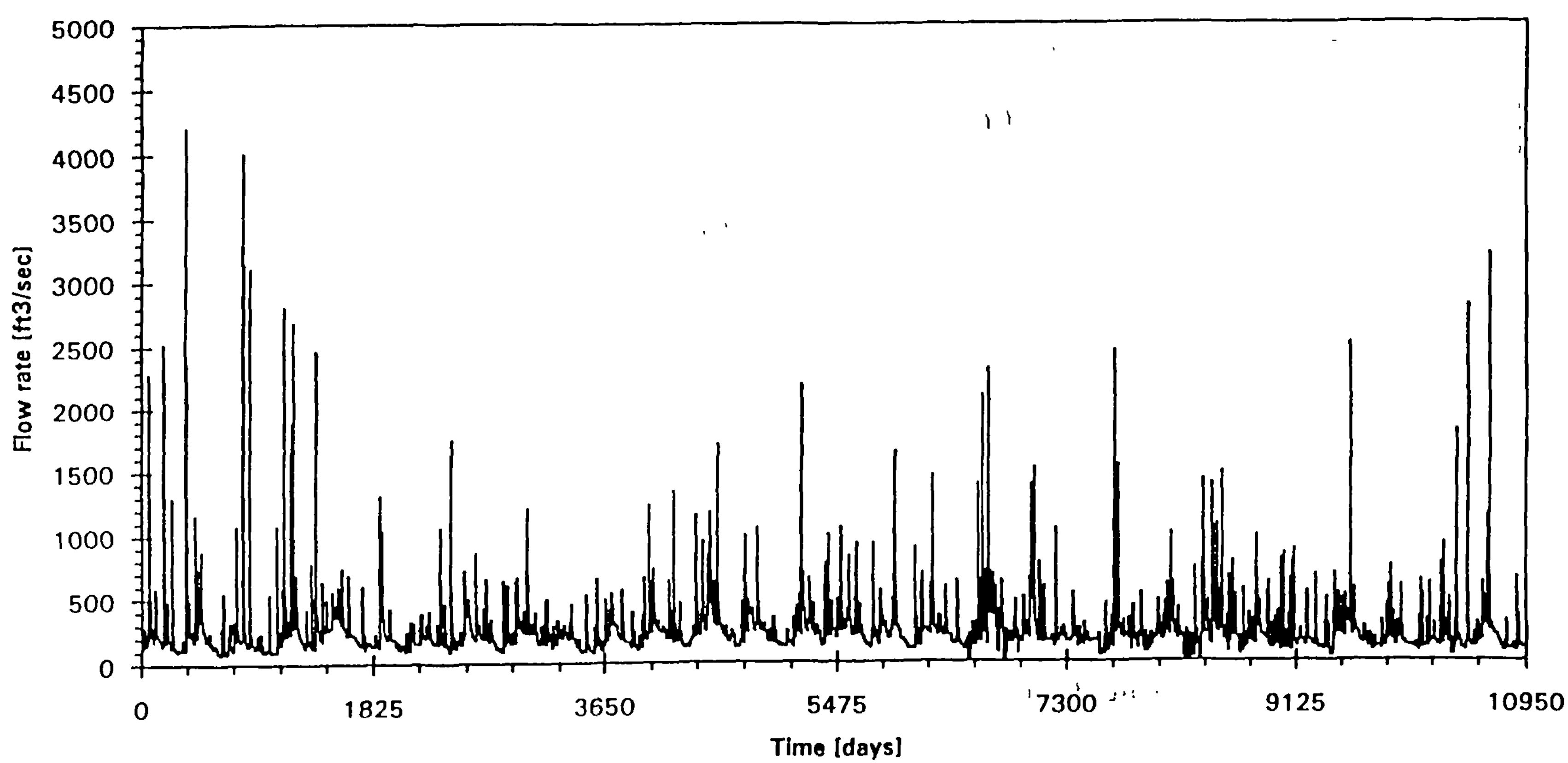

Figure 7. Observed vs. predicted channel profiles

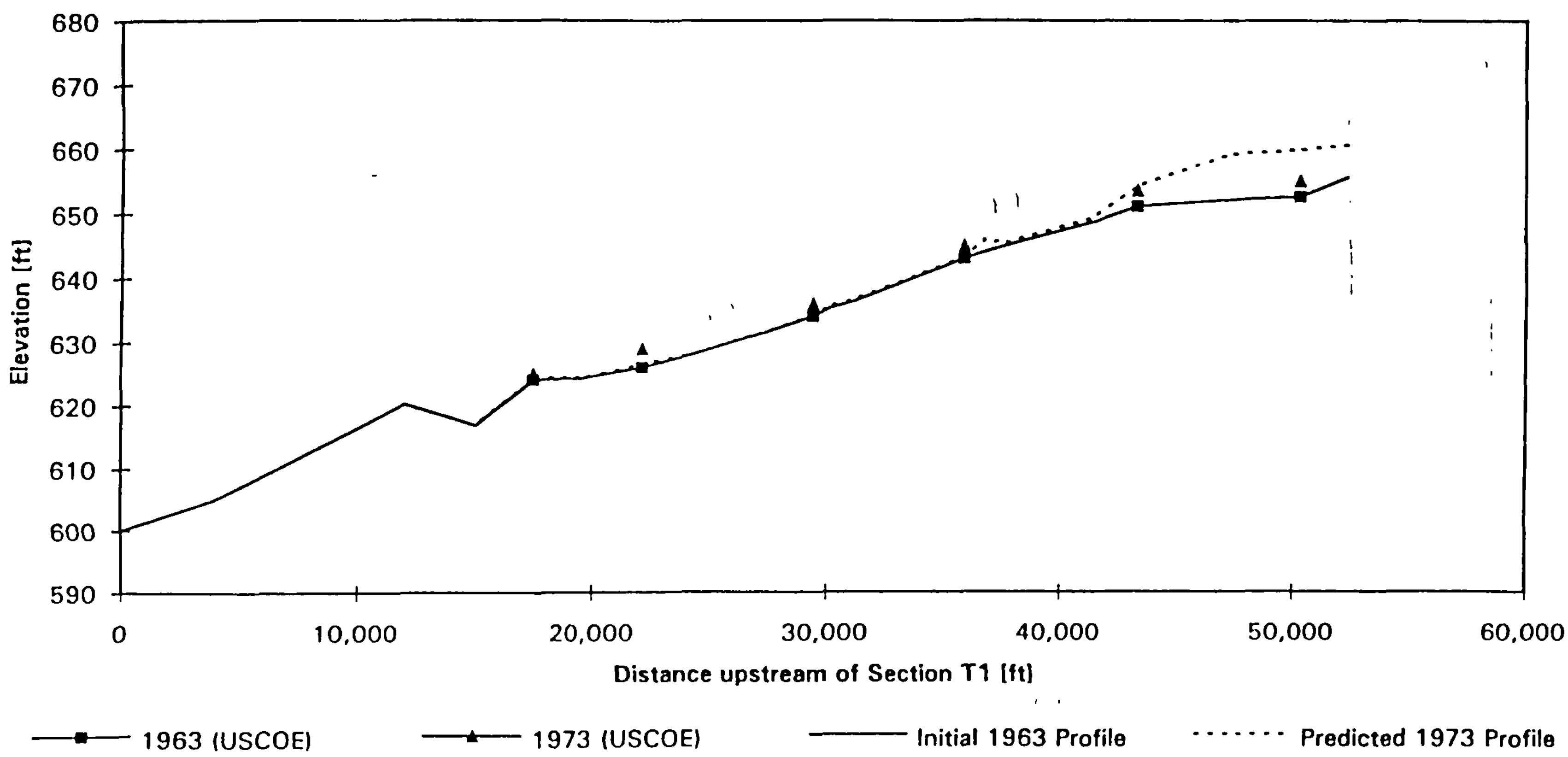

Figure 8. Predicted channel profiles, 30-year simulation

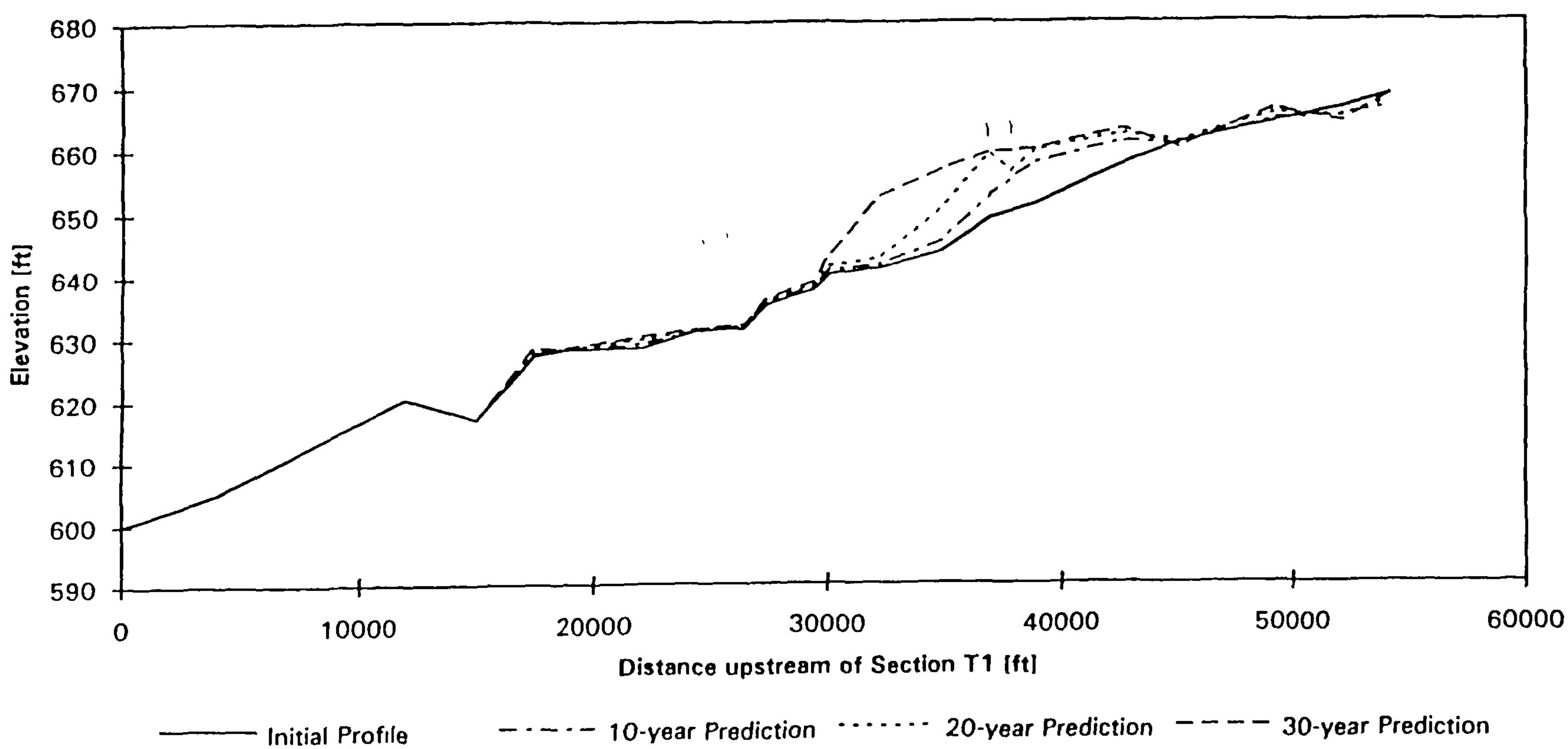

Figure 9. Deposition history at selected transects